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In This Issue

It is a thing of no great difficulty to raise objections against another man's oration—nay, it is a very easy matter; but to produce a better in its place is a work extremely troublesome. Plutarch (A.D. 46-120)

It is with some apprehension but with a great deal of enthusiasm that we assume the economics editorship of *The Journal of Agricultural Economics Research*. In the 43 years that *JAER* has been published, many changes have shaped the world and agriculture in particular. But one constant has been the imagination, dedication, and leadership displayed by the past editors of *JAER*. All of these individuals, from Howard Parsons and Caroline Sherman to our immediate predecessor, Gene Wunderlich, have played an important role in shaping, nurturing, and guiding the journal. In particular, we would like to single out Gene for his hard work and innovations. We believe our founder, O.V. Wells, would be especially pleased with the evolution of the journal. We will do our best to uphold these traditions. We also look forward to working with Jim Carlin, the managing editor, whose tireless efforts and institutional memory will help ensure that the standards of the journal will be upheld.

Our inaugural issue contains four articles and a like number of book reviews. The first article by Blaine, Randall, and Mohammad presents a theoretical framework for examining the demand for land information systems (LIS) services under conditions of uncertainty. Their framework focuses on the use and value of LIS to a potential purchaser of real estate. In doing so, they address the theoretical properties of the demand for and benefits of land information. Their approach is to start with a hedonic bid-rent land market model and modify it to include an expected utility function and allow for information (obtained at a cost) to alter prior probabilities of land having particular attribute values. This research represents a step forward in the conceptual modeling of the demand for LIS and should provide a useful framework for future empirical work in this area.

Reed studies the role of producer expectations about demand shifts in milk supply response by using a dynamic equilibrium model of the dairy economy. Unlike the traditional Marshallian dichotomy of supply and demand, this study suggests that supply response depends critically on the assumption of expectations that producers hold about demand shifts. In other words, supply response is fundamentally intertwined with consumer demand. Understanding how producer expectations about demand shifts affect the dairy economy is fundamental to analyses of such current issues as changing demand due to generic promotion and health concerns. It certainly appears to be much more complex than traditional models of supply response and leads to different interpretations of the available data.

Villezca-Becerra and Shumway report very detailed cross-price production elasticities for four major agricultural States (California, Iowa, Texas, and Florida). Cross-price elasticities are reported for as many as 25 individual crop and livestock output supplies and six factor inputs. Their effort to model the complex market interactions with only 36 annual observations is facilitated by nonparametric separability tests that allow them to reduce the number of independent parameters by aggregating some of the output and input categories and by performing multistage modeling. The detailed estimates presented in this paper will be especially useful for those analyzing distributional consequences of various agricultural programs and policies.

Yee examines the rate of return to both public and private investment in agricultural research in the first published study that we know of to estimate rates of return to private investment in agricultural research. The study finds that returns may be similarly substantial for private and public research. The rate of return to public research is an estimated 49 percent compared with 38 percent for private research. While returns to private research are about one-quarter less than public research, most researchers and policymakers would agree that these returns are quite high. In 1990, USDA spent about $1 billion for agricultural research and development. Yee contends that this is public money well spent.

Paarlberg's review of D. Gale Johnson's book *World Agriculture in Disarray* opens with the rhetorical questions "Why a second edition?" and "Aren't some classics better left unaltered?" Paarlberg dismisses these questions and believes the second edition may be of greatest value to students of the original. He believes the discussion of the scholarly work that models and quantifies the various international market distortions since 1973 will be of particular interest to economists. While highly complimentary, Paarlberg believes Johnson may be placing too much faith on GATT as a venue for farm policy reform. Paarlberg would prefer more emphasis on disadvantageous terms of trade imposed on farmers by governments in developing countries.

Thiesenhusen's review of *Agrarian Reform and Grassroots Development: Ten Case Studies* ends with "This book should be studied by those interested in agricultural development," a recommendation to be taken seriously. From Thiesenhusen's vantage point, the major message from the series of essays is that there is no one model for agrarian reform and that reforms are by their very nature untidy. He observes that "there is often more political mileage to be obtained from distributing land than from assisting beneficiaries to produce on that property." Compliments aside, Thiesenhusen would have liked to see more microstudies in the book and more emphasis on income distribution and employment creation.

Hyde states that he rapidly became an enthusiastic reader of Floro and Yotopoulos's book *Informal Credit Markets and the New Institutional Economics: The Case of Philippine Agriculture*. The book provides an empirical assessment of rural credit within the framework of information economics or the New Institutional Economics (NIE). Hyde was pleased by the conclusion "that formal and informal sector lenders are complements, not the substitutes usually assumed by central governments...and many neo-classical economists." While unsure that the book needs all the kind words about NIE and could be improved by a discussion of the authors' own general reflections on the equity problem they raise, Hyde is convinced the volume presents a scientifically rigorous discussion of the principal actors in the Philippine market for rural credit.

Dickason tackles McCloskey's *If You're So Smart*. Dickason finds that McCloskey's clear writing style certainly helps in communicating the compelling, but controversial, argument that "modern economists' analytical results obtained through purely objective data observations and highly refined mathematical logic tend to be merely of abstract academic interest." Enough said; now decide for yourself.

James Blaylock
David Smallwood

The Demand for Land Information System Services: A Theoretical Framework

Thomas W. Blaine, Alan Randall, and Golam Mohammad

Abstract. *A comparative statics analysis shows that a compensated demand for LIS services exists. The theoretically correct welfare measure under certainty, the Hicksian compensating variation, is appropriate to the willingness to pay for land information. The value of this information is proportional to the utility of the land-related amenity whose amount is uncertain and the increment in the probability of a desirable outcome owing to the information signal* ex ante. *The effect of initial uncertainty upon information demand is ambiguous, but information demand is strictly an increasing function of the perceived accuracy of the LIS.*

Keywords. *Land Information Systems (LIS), hedonic model, uncertainty, amenity, Hicksian compensating variation.*

In applying the appropriate theoretical framework, we are able to work through comparative statics to identify the precise properties of the demand for land information relevant to the estimation of benefits of LIS services. We used a hedonic bid-rent land market model, incorporated a discrete, two-state expected utility function, and allowed for information, obtained at a cost, to alter prior probabilities. We chose the discrete model, even though the results extend to the continuous case, for simplicity and because some types of land information actually take discrete binary values (for example, the title is or is not secure).

The Hedonic Land Market Model Under Certainty

In the tradition of Alonso (1964) and Rosen (1974), posit an individual utility function of the form U = U(x,h,q), where x is the composite market good, h is land space occupied, and q is a vector of amenities associated with h.[1,2] The utility function is concave and strictly increasing in x, h, and all q. The price of land space is $r_h(q)$. That is, the implicit prices of amenities associated with land are capitalized into the value of the land.

The individual's behavior is posited as:

$$\text{Max } U = U(x,h,q) \text{ subject to: } I = r_x x + r_h(q)h, \quad (1)$$

where I is a measure of income, and r_x is the price of the composite bundle, x.

Among others, a first-order condition emerges from this:

$$(\partial U/\partial q_k)/(\partial U/\partial x) = (\partial r_h/\partial q_k)\,(h/r_x). \quad (2)$$

In equation 2, equilibrium requires that the individual equates the marginal value of the k^{th} amenity with the increment in land cost associated with the amenity. The marginal rate of substitution between each amenity and the composite commodity is equated with the ratio of the implicit price of the amenity to the price of the composite commodity. This equality characterizes not only individual equilibrium but market equilibrium as well. A fundamental tenet of the bid-rent approach is that there are no suppliers of land, only demanders. The person who sells land is simply one demander who has been outbid by another. The theory thus provides the basis for estimating the market values of particular characteristics of land parcels, ranging from onsite attributes to public goods provided over an area, all of which bear implicit prices capitalized into the market values of parcels. The price $r_h(q)$ serves a dual purpose, however. It not only capitalizes the value of the amenity q, but it also rations space, h.

The appropriateness of the hedonic framework for analyzing land markets (especially farmland) has been questioned in the literature over the issue of whether land markets efficiently capitalize the values of amenities, such as soil depth and productivity (Crosson, 1982; Eberle, 1988; Miranowski and Hammes, 1984). This issue has implications for fundamental natural resource allocation issues primarily centering around soil erosion. Miranowski and Hammes's results were consistent with efficient capitalization, but Eberle indicated that the farm real estate market is not efficiently capitalizing soil productivity into the sale price of farmland. Eberle and Crosson both attributed this to a lack of market information. Modernized LIS can provide

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[1]Lancaster (1966) has been credited with formalizing the model where goods are explicitly described by a vector of characteristics.

[2]Sources are listed in the references section at the end of this article.

The Evolution of LIS

Over the past decade, a great deal of literature has emerged outlining the procedures, standards, capacity, and technology for multipurpose cadastres, or land information systems (LIS). Modernized LIS, subsets of Geographic Information Systems (GIS), are typically based upon a geodetic reference frame, with a base map, overlays, and registers that allow individual land parcels to be identified. Data files are linked to parcel identifiers. These files may include any amount and type of information, such as easements, liens, landownership, use, value, zoning, soil type, and drainage. For a thorough description of modernized LIS, see McLaughlin (1975) and the National Research Council (1980, 1983). Much of this work has been spearheaded by geodetic scientists, civil engineers, and surveyors. With increasing frequency, these professionals have been citing in their reports the need for a research program designed to delineate and measure the benefits of LIS services. In outlining research needs in the area, Robbins and Grasskamp (1985, p. 11) stated, "It is proposed that research be conducted to identify the specific user requirements for land information services and products." In the same workshop, Crossfield (1985, p. 32) was even more specific:

> The land information community develops products and services that sustain a variety of land planning, investment, and development activities. For years the land information community has asserted that the economic value derived from use of these products and services in decisionmaking exceeds the cost of generating them. However, it has lacked the analytic tools to substantiate its claim.... The challenge to the land information community is to develop, with members of other disciplines, methods that provide to those who control public and private resources the means to value the benefits of an investment in land information systems.

While these research needs have been recognized by noneconomists in the LIS community, economists have progressed in modeling decisions under uncertainty and the role of information in decisionmaking. Yet, most of the economics of LIS has heretofore been confined to the calculation of potential cost savings to public agencies of improved mapping, recording, and access of information (Dickinson and Calkins, 1988; Epstein and Duchesneau, 1984; Larsen, 1971). Much of this work has assumed the existence of a downward sloping demand for information, but has provided neither a theoretical framework for its derivation nor a precise catalog of its properties (Wunderlich and Moyer, 1984).

the precise type of information necessary to improve land market efficiency. The model developed in this article does not address the issue of overall market efficiency, or whether efficiency can be attained at a lower cost through market dissemination of information as opposed to government control of information in conjunction with regulation. Instead, we consider the individual purchaser of real estate as the judge of value, and from that premise, we derive the theoretical measure of the value the purchaser places upon information of this nature. This framework lays the foundation for answering the broader questions of overall efficiency.

The General Hedonic Model Under Uncertainty

Models of decision under uncertainty, along with the incorporation of information, have substantial history in the literature (Eiselt and Langley, 1990; Hirshleifer and Riley, 1979; Schoemaker, 1982). A longstanding distinction between risk and uncertainty can be traced to Knight (1921). This distinction hinges upon whether the decisionmaker is able to calculate probability measures associated with unknown outcomes. If the decisionmaker cannot calculate such probabilities, the situation is labeled uncertainty. Modeling within this context has given rise to such decision criteria as the maximum rule, maximax, and minimax regret, and has influenced the development of social philosophies (Rawls, 1971). In circumstances where the individual *can* assign probabilities, the structure is labeled risk. Modeling within this framework has yielded a rich literature in expected utility dating from von Neumann and Morgenstern (1947). In light of recent developments, however, the risk-uncertainty distinction may be regarded as a matter of degree rather than of kind (Eiselt and Langley, 1990). Our nomenclature in this article is "decision under uncertainty."

In the standard model, an individual is faced with maximizing a payoff function that depends upon a control variable and a random variable. Before choosing a value for the control variable (the termi-

nal decision), the decisionmaker must decide whether to acquire information on the expected value of the random variable (the nonterminal decision). The information acquisition decision, as modeled in an explicit search process, has significantly affected the derivation of optimal search strategies and stopping rules (Kohn and Shavell, 1974; Morgan and Manning, 1985). These approaches eschew the use of entropy-based measures of information (Shannon, 1948) in favor of using parameters associated with probability distributions (Hart, 1973; Horowitz and Horowitz, 1976). The purchaser of information is never in a position to buy a specific message or signal but must buy a set of information services which reveal signals that subsequently allow a revision of prior probability distributions (Hirshleifer and Riley, 1979).

Kihlstrom (1974) applied a more standard neoclassical approach to modeling information demand within the Lancastrian context. He assumed that the characteristic vector associated with each market good is not known precisely but varies on the basis of some random fluctuation. He conceptualized information as a set of signals correlated with the amount of each characteristic contained in each market good. Positing income-constrained expected-utility-maximizing behavior, he was able to derive a system of demand functions for commodities and information from a single Lagrange equation. In addition, he used an income compensation approach to arrive at the corresponding income-compensated demand functions, showing that the Slutsky matrix for information demand is symmetric and negative-definite.

Our model identifies the use and value, along with the properties of the demand for and benefits of, land information to a potential purchaser of real estate. This model extends Kihlstrom's (1974) for the general hedonic case to the hedonic bid-rent theory of the land market. By furnishing a more specific interpretation of information than Kihlstrom's model, our model (in his words) allows "for a broad range of interpretations."

The Hedonic Land Market Model Under Uncertainty

Consider a composite attribute, q, associated with land space h. Allow two levels of q to exist, q_1 and q_2, with $q_2 > q_1$. An individual who considers parcels for purchase is unsure of the level of q associated with each parcel, but is able to form prior probabilities. This model does not specify the manner in which the individual forms these prior probabilities. One conceivable way would be on the basis of general information concerning the proportion of parcels that contain q_2 as opposed to q_1. The model is specific in terms of the way the probabilities achieve significance to the individual, who expects that a parcel purchased at random produces a probability, p_2 and p_1, of receiving amenity levels, q_2 and q_1. In a general sense, p_2 and p_1 may be interpreted as success and failure probabilities, with $p_2 + p_1 = 1$.

Whereas in equation 1 amenity values were perfectly capitalized into parcel values, in a world of uncertainty they are capitalized only in a probabilistic sense, or not at all. Allowing for partial capitalization (probabilistic) does not change the fundamental results of this analysis, but it does complicate the algebra. The model chosen for the exercise below considers a complete lack of capitalization, while the foundation of the partial capitalization model is presented in the appendix.

The individual is posited to behave as an income-constrained expected-utility maximizer. Establish the Lagrange equation:

$$Z = p_1\, U(x,h,q_1) + p_2\, U(x,h,q_2) + \lambda[I - r_1x - r_2h]. \quad (3)$$

The first-order conditions are:

$$\begin{aligned} &a)\ Z_x = p_1U_x^1 + p_2U_x^2 - \lambda r_1 = 0, \\ &b)\ Z_h = p_1U_h^1 + p_2U_h^2 - \lambda r_2 = 0, \text{ and} \\ &c)\ Z_\lambda = I - r_1x - r_2h = 0, \end{aligned} \quad (4)$$

where U_x^1 is the marginal utility of x with $q = q_1$, and so on.

Totally differentiate equation 4 and place in matrix form:

$$\begin{bmatrix} p_1U_{xx}^1 + p_2U_{xx}^2 & p_1U_{xh}^1 + p_2U_{xh}^2 & -r_1 \\ p_1U_{hx}^1 + p_2U_{hx}^2 & p_1U_{hh}^1 + p_2U_{hh}^2 & -r_2 \\ -r_1 & -r_2 & 0 \end{bmatrix} \begin{bmatrix} dx \\ dh \\ d\lambda \end{bmatrix} = \begin{bmatrix} (U_x^1 - U_x^2)dp_2 + \lambda dr_1 \\ (U_h^1 - U_h^2)dp_2 + \lambda dr_2 \\ -dI + xdr_1 + hdr_2 \end{bmatrix} \quad (5)$$

The 3 × 3 matrix on the left-hand side is the bordered hessian whose determinant must be positive to ensure a maximum for equation 3. This determinant and its sign will prove critical to the derivation of the properties for the demand for information below.

Now allow for the existence of an information source, E, to be available in continuous amounts at unit price r_3. The function of E is to alter the prior

probabilities, p_1 and p_2. Specifically, E contains parcel-special messages correlated with the true levels of q associated with the parcel(s) under consideration.

The posterior probability distribution is a function of the endogenous information demand, E. Note that the probabilities, p_1 and p_2, are *not* probabilities corresponding with the likelihood of an individual parcel having the respective amenity levels. Rather, they enter into the expected utility function as probabilities that the individual will ultimately choose a parcel with these amenity levels. While the messages associated with information purchase reveal parcel-specific probabilities, the individual is able to alter the success-failure probabilities present in the expected utility function by utilizing the information in making the purchase decision.

By Bayes's theorem, the probability that any specific parcel i, contains amenity level j, given LIS signal z, is:

$$p(ij \mid z) = p(j \mid z) = \frac{p(z \mid j)\ p(j)}{p(z)}. \tag{6}$$

The probability $p(z \mid j)$ is the likelihood function associated with the LIS, the probability of receiving signal z given that the parcel contains amenity level j. The term p(j) is the unconditional probability that the parcel contains amenity level j, and is identical to the interpretation given to the prior probabilities in equation 3. The denominator, p(z), is the unconditional probability of receiving signal z, and is related to the likelihood function by:

$$p(z) = \sum_{j=1}^{2} p(z \mid j) \cdot p(j), \tag{7}$$

given the two-state nature of the problem considered here. It is important to note that signals (z) need not take discrete binary values associated with amenity levels 1 and 2. Signals may take a wide variety of forms, some of which may require a great degree of expertise in interpretation. The current title search and appraisal industries exist today largely due to the amount of professional expertise necessary in interpreting information signals contained in public land records, which themselves are open access items. Whether modernized LIS will reduce the amount of expertise necessary in reviewing and interpreting land records remains to be seen.

After having purchased the LIS package, E, the individual is able to revise the success/failure probability distribution. Let the posterior distribution be $p_1(E,\alpha) + p_2(E,\alpha) = 1$, where α is an exogenous parameter associated with the distribution, establishing the prior probabilities as well as influencing the rate at which the posterior probabilities are affected by information package E. Note that if no information is used (E=0), then the posterior probabilities collapse to the prior probabilities, for example, $p_2(0,\alpha) = p_2$. The Lagrange equation[3] now becomes:

$$L = p_1(E,\alpha)\ U(x,h,q_1) + p_2(E,\alpha)\ U(x,h,q_2) + \lambda[I - r_1x - r_2h - r_3E]. \tag{8}$$

The first-order conditions are:

$$\text{(a) } L_x = p_1(E,\alpha)U_x^1 + p_2(E,\alpha)U_x^2 - \lambda r_1 = 0$$

$$\text{(b) } L_h = p_1(E,\alpha)U_h^1 + p_2(E,\alpha)U_h^2 - \lambda r_2 = 0$$

$$\text{(c) } L_e = (dp_1/dE)U^1(\cdot) + (dp_2/dE)U^2(\cdot) - \lambda r_3 = 0$$

$$\text{(d) } L_\lambda = I - r_1x - r_2x - r_3E = 0. \tag{9}$$

$U^1(\cdot)$ and $U^2(\cdot)$ are total utility levels at $q = q_1$ and $q = q_2$. Since $q_2 > q_1$, $U^2(\cdot) - U^1(\cdot) > 0$ is the discrete utility change associated with raising q from q_1 to q_2, the value of the increment in the amenity in utility terms, denoted V_q. Similarly, U_x^1 is the marginal utility of x evaluated at $q = q_1$, and so on. If x and q are gross complements, then $U_x^2 > U_x^1$. The inequality is reversed if they are gross substitutes. The same interpretation holds for U_h^1 and U_h^2.

Note condition (9c). Since $-dp_1/dE = dp_2/dE$, we get:

$$[U^2(\cdot) - U^1(\cdot)]\ dp_2/dE = \lambda r_3 = V_q\ dp_2/dE.$$

[3]As indicated previously, two distinct approaches have evolved regarding modeling the demand for information: the explicit *sequential* model (Kohn and Shavell, 1974), and the *timeless* neoclassical model (Kihlstrom, 1974). We follow the latter because it offers distinct advantages over the former. First, it produces a demand function for information which is a *derived* demand, strictly taken from the demand for land-related amenities. Second, the demand function has properties that are neoclassical. This static framework, of course, does not mean to deny the sequential aspect of the choice problem. This is not revolutionary. For example, the standard neoclassical profit maximization model is stated in a single equation:

$$\text{Profit} = P\ f(X) - w\ X.$$

Clearly, inputs X must be purchased (at prices w) before output (at quantity) f(X() can be produced and sold (at price P). Yet, the entire process is modeled in a single equation. The neoclassical framework allows us to abstract from time and to derive a demand function for inputs X(P,w) from the profit function. Moreover, it allows us to identify the properties of that demand function. The analogy here is exact. Application of the neoclassical framework to the LIS problem allows us to obtain a demand function for information which is derived from the demand for land-related amenities and to identify its properties.

Since $U^2(\cdot) - U^1(\cdot) > 0$, and $\lambda r_3 > 0$, we know that dp_2/dE must be greater than zero. That is, information is demanded only to the extent that it raises the probability that the individual will make a choice that will ultimately have favorable results in terms of q, *ceteris paribus*. The condition states that the individual purchases more information as long as the gain in expected utility exceeds the marginal cost of the information.

The standard definition of value of information is the difference in the expected utility obtained with information versus without it (Gould, 1974). The distinction is occasionally made between perfect and imperfect information. Under the perfect information, expected utility collapses to actual utility, where all variables are known with certainty once the information has been acquired. In the context of our model, the information signal is imperfect so long as the strict inequality, $p_2(E,\alpha) < 1$, holds for all values of E. Note that there is nothing in (9c) or in the standard definition of information value that requires that information cause a change in the terminal decision in order to acquire value. That is, it is possible that the solution to equation 3 might involve a land purchase identical to one obtained by equation 8, even with a positive amount of information demanded, because both the information purchase decision and the expected utility measurement are made *ex ante*. The first-order conditions derived above require that the value of the marginal information signal is proportional to the product of:

(a) the incremental value of the amenity whose amount is uncertain, and

(b) the marginal success probability of information.

Thus, if information does not change the terminal decision, it must at least raise the individual's perception of success probability, p_2, going into the decision. If indeed the parcel purchased under equation 3 is identical to that implied by equation 8, the individual must feel more confident in the latter case for the information to have value. In a sense, information is valuable in this type of situation for reinforcing what the individual already believes. While information need not change the terminal decision, it must have relevance to that decision. That is, this model does not allow for an existence value for information since the demand for E is strictly derived from the demand for the amenity, q.

To analyze the comparative statics of the model, totally differentiate [9(a) – 9(d)], set $dp_1 = -dp_2$, and place in matrix form:

$$\begin{bmatrix} p_1U^1_{xx} + p_2U^2_{xx} & p_1U^1_{xh} + p_2U^2_{xh} & (U^2_x - U^1_x)\dfrac{dp_2}{dE} & -r_1 \\ p_1U^1_{xh} + p_2U^2_{hx} & p_1U^1_{hh} + p_2U^2_{hh} & (U^2_h - U^1_h)\dfrac{dp_2}{dE} & -r_2 \\ (U^2_x - U^1_x)\dfrac{dp_2}{dE} & (U^2_h - U^1_h)\dfrac{dp_2}{dE} & (U^2 - U^1)\dfrac{d^2p_2}{dE} & -r_3 \\ -r_1 & -r_2 & -r_3 & 0 \end{bmatrix} \times \begin{bmatrix} dx \\ dh \\ dE \\ d\lambda \end{bmatrix} = \begin{bmatrix} \lambda dr_1 + (U^1_x - U^2_x)\dfrac{dp_2}{d\alpha}d\alpha \\ \lambda dr_2 + (U^1_h - U^2_h)\dfrac{dp_2}{d\alpha}d\alpha \\ \lambda dr_3 + (U^1 - U^2)\dfrac{d^2p_2}{ded\alpha}d\alpha \\ -dI + xdr_1 + hdr_2 + Edr_3 \end{bmatrix} \tag{10}$$

The 4×4 matrix above is the bordered hessian whose determinant (H) must be negative by the second-order conditions associated with a maximum for equation 8. Cramer's rule may be used to discern the properties of the demand for information $E(\cdot)$.

To examine the own-price effect of the demand for information ($\partial E/\partial r_3$), set $dr_1 = dr_2 = dI = d\alpha = 0$ to get:

$$\frac{\partial E}{\partial r_3} = \frac{\lambda A_{33}}{H} - \frac{EA_{43}}{H}. \tag{11}$$

The denominator in each right-hand side term (H) is strictly negative, as discussed above. The term A_{33} is the determinant:

$$A_{33} = \begin{vmatrix} p_1U^1_{xx} + p_2U^2_{xx} & p_1U^1_{xh} + p_1U^2_{xh} & -r_1 \\ p_1U^1_{hx} + p_2U^2_{hx} & p_1U^1_{hh} + p_1U^2_{hh} & -r_2 \\ -r_1 & -r_2 & 0 \end{vmatrix}$$

This is the bordered hessian determinant whose sign must be strictly positive to ensure a maximum for equation 3 above. Since λ, the marginal utility of income, is positive, the first term on the right-hand side of equation 11 is strictly negative. The sign on the second right-hand side term $-\dfrac{EA_{43}}{H}$ depends upon the sign of the determinant A_{43}:

$$A_{43} = \begin{vmatrix} p_1U^1_{xx} + p_2U^2_{xx} & p_1U^1_{xh} + p_2U^2_{xh} & -r_1 \\ p_1U^1_{hx} + p_2U^2_{hx} & p_1U^1_{hh} + p_2U^2_{hh} & -r_2 \\ (U^2_x - U^1_x)\dfrac{dp_2}{dE} & (U^2_h - U^1_h)\dfrac{dp_2}{dE} & -r_3 \end{vmatrix}$$

Inspecting equation 10 shows that $\frac{A_{43}}{H}$ is identical to $\frac{\partial E}{\partial I}$, the partial of the demand for information with respect to income. The sign on this term is ambiguous, depending on whether land information is a normal or inferior good. Equation 11 is a Slutsky equation for land information. The proof that the term $\frac{\lambda A_{33}}{H}$ is strictly analogous to the inverse slope of a compensated demand function (the direct substitution effect) for land information is straightforward, and is omitted here, but may be shown by establishing the dual to equation 8:

$$N = r_1 x + r_2 h + r_3 E + \mu[U - p_1(E,\alpha)U(x,h,q_1) - p_2(E,\alpha)U(x,h,q_2)], \quad (12)$$

and proceeding by way of the comparative statics. The resulting compensated demand function for information may be expressed as: $\varepsilon = \varepsilon(r_1, r_2, r_3, \alpha, U)$,

with $\partial\varepsilon/\partial r_3 = \frac{\lambda A_{33}}{H} < 0$.

The compensating variation (CV), or willingness to pay for a price reduction in LIS services from r_3^0 to r_3^1 is:

$$CV = \int_{r_3^1}^{r_3^0} \varepsilon(r_1, r_2, r_3, \alpha, U) dr_3 . \quad (13)$$

The Effect of Initial Uncertainty and Increased Accuracy Upon LIS Demand

Numerous questions have been raised concerning rates of change of information demand and value with respect to changes in exogenous variables. Some of the results have been counterintuitive. Gould (1974), for example, showed that, in general, riskier probability distributions do not increase the *ex ante* value of information. One of the problems was the issue of developing a unique definition of risk. The model presented here offers definitions of risk as well as perceived accuracy of the LIS source by way of the parameter α. The question we address is whether we can obtain unambiguous signs on the effects of initial uncertainty and perceived accuracy of the LIS source upon the demand for LIS services.

In equation 10, the term, α, appears in two separate differential forms. The term, $dp_2/d\alpha$, is the rate of change of the success probability with respect to α independent of any information, and is properly interpreted in terms of initial uncertainty. For $dp_2/d\alpha > 0$ or $dp_2/d\alpha < 0$, an increase in α implies, respectively, a greater or smaller probability of success *a priori*.

The second-order term, $d^2p_2/dEd\alpha$, is the rate of change in the success probability due to an increase in information acquisition changes with respect to α. If $d^2p_2/dEd\alpha > 0$, (< 0), then an increase in α means that the success probability rises more (less) rapidly per unit of E consumed, indicating an increase (decrease) in the perceived accuracy of the LIS.

From equation 10, set $d^2p_2/dEd\alpha = dr_1 = dr_2 = dr_3 = dI = 0$, and we can use Cramer's rule to get $\partial E/\partial\alpha$

$$= \frac{(U_x^1 - U_x^2)(dp_2/d\alpha) A_{13} - (U_h^1 - U_h^2)(dp_2/d\alpha) A_{23}}{H} .$$

The sign on this term is ambiguous, depending upon the gross complimentary of the amenity, q, with the composite good (x) and land space (h), and the signs of the minors A_{13} and A_{23}. This would seem to be a corroboration of Gould's result in terms of information demand. We cannot specify in what manner changes in the initial probability distribution affect information demand.

With respect to perceived accuracy, set:

$dp_2/d\alpha = dr_1 = dr_2 = dr_3 = dI = 0$, and use Cramer's rule to get:

$$\partial E/\partial\alpha = [U^1(\cdot) - U^2(\cdot)] \frac{A_{33}}{H} d^2p_2/d\varepsilon d\alpha.$$

Recall that $\partial\varepsilon/\partial r_3 = \lambda \frac{A_{33}}{H}$, and $[U^2(\cdot) - U^1(\cdot)] = V_q$.

Substitution yields:

$$\partial E/\partial\alpha = -\frac{V_q}{\lambda} (\partial\varepsilon/\partial r_3) d^2p_2/dEd\alpha.$$

Since V_q and λ are strictly positive, while $\partial\varepsilon/\partial r_3$, the Hicksian own-price effect for information demand, is strictly negative, it follows that $\partial E/\partial\alpha > (<) 0$ for all $d^2p_2/dEd\alpha > (<) 0$. The rate of change in information demand with respect to an increase (decrease) in perceived information accuracy is strictly positive (negative), a function of the incremental value of the uncertain amenity (V_q), the marginal utility of income, the inverse slope of the compensated demand curve, and the rate of change in perceived accuracy.

Conclusions

A demand for LIS services may be derived from the demand for land-related amenities within the context of the hedonic land market model under uncer-

tainty. The LIS demand derived here possesses properties similar to those of typical market goods under certainty. Moreover, the rate of change in demand for LIS services increases with increased perceived accuracy in the system. This response relates to the value, in utility terms, of an amenity whose amount is uncertain, the marginal utility of income, and the inverse slope of the compensated demand function for information.

At the theoretical level, the model may be expanded to account explicitly for information about multiple and independent amenities in the amenity (q) vector. Given that our model is implicitly based on a search process, a more explicit search model may be an appropriate innovation.

This framework provides a basis for specifying an empirical model for estimation of the demand and value of land information. Three general possibilities are immediately obvious. First, if voluntary purchases of land and land information are observable, econometric analysis of the derived demand for land information should be feasible. This condition may well be met for, say, soil tests, but perhaps not for title information, which public agencies and lenders typically require. Second, hedonic analysis of the demand for land information may be feasible, if there is spatial variation in the amount of information provided by sellers of land. Third, a contingent valuation approach would allow valuation of a considerable array of presently available and alternative land information services.

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Appendix

We may allow for partial (probabilistic) capitalization of amenity values by specifying r_2, the price of land, as a function of success probability, p_2. Recall that, in addition to capitalizing amenity values, r_2 also rations space. Let ϕ be an exogenous scarcity parameter associated with generic space h. Thus the hedonic price function under uncertainty is expressed as $r_2(p_2, \phi)$ with partial derivatives greater than zero. The individual is posited to behave as an income-constrained expected-utility maximizer. Thus, the relevant Lagrange equation becomes:

$$L = p_1(E,\alpha)\,U(x,h,q_1) + p_2(E,\alpha)\,U(x,h,q_2) + \lambda[I - r_1x - r_2(p_2,\phi)h - r_3E]. \tag{A1}$$

The first-order conditions are:

$$\text{(a) } L_x = p_1U_x^1 + p_2U_x^2 - \lambda r_1 = 0$$

$$\text{(b) } L_h = p_1U_h^1 + p_2U_h^2 - \lambda r_2(p_2,\phi) = 0$$

$$\text{(c) } L_e = [U^2(\cdot) - U^1(\cdot)](dp_2/dE) - \lambda r_3 = 0$$

$$\text{(d) } Lp_2 = [U^2(\cdot) - U^1(\cdot)] - \lambda\,(dr_2/dp_2)h = 0$$

$$\text{(e) } L_\lambda = I - r_1x - r_2(p_2,\phi)h - r_3E = 0. \tag{A2}$$

Dividing condition A2(d) by A2(c), canceling terms, and rearranging yields:

$$(r_3)/dp_2/dE) = (dr_2/dp_2)h.$$

In equilibrium, the individual equates the ratio of the marginal benefits of information acquired from the two sources, r_2 and E, with the ratio of the marginal costs. In other words, the net gain in success probability, p_2, associated with the purchase of a more expensive property is balanced against the net gain associated with the purchase of the information service, E. The individual optimizes at the point where an additional dollar's worth of information service provides the same increment in p_2 as an additional dollar's purchase price per unit of space h.

Expectations, Demand Shifts, and Milk Supply Response

A.J. Reed

Abstract. *The demand for dairy products shifted during the past decade to items with less fat. This, along with a dairy surplus, has led to a generic advertising campaign by the industry. Consumers have responded by increasing dairy product purchases, while changes in the provisions of the dairy support program have altered Government demands as well. This study compares effects of a shift in demand under two different assumptions regarding producer expectations.*

Keywords. *Demand shifts, rational expectations, static expectations, dynamic programming, bootstrap estimation, inequality restrictions.*

Over the past decade, shifts in the demand for dairy products have altered the state of the dairy economy. For example, since generic advertising began in 1984, fluid milk sales have increased an estimated 4.4 percent and cheese sales an estimated 2.25 percent through 1990 (Blaylock and Blisard, 1988).[1] New, lower fat products that reflect consumers' health concerns have been introduced into the market. Understanding how such demand shifts affect the dairy economy is critical to understanding its reaction to a change in policy. The effect of a shift in demand on the state of the dairy economy is examined within a dynamic general equilibrium framework (see Liu and Forker (1990) for an example of a general equilibrium analysis).

To illustrate the appropriateness of a general equilibrium analysis, consider the effect on supply of a positive shift in demand for dairy products. Since the dairy herd management is inherently dynamic, a milk supply decision taken today affects future profits. Hence, if the shift in demand results in dairy farmers expecting to receive permanently higher milk prices, milk supply might increase, farm prices might fall, and government purchases might increase. If farmers expect only transitory increases in the price of milk, supply might change very little, higher farm prices might be realized, and government purchases might fall. This scenario shows that expectations are a key component of a dynamic general equilibrium analysis. A rational-expectations supply response to a demand shift depends critically on the distribution of the demand shift. A naive-expectations supply response ignores the distribution of the demand shift. Liu and Forker assumed expectations are naive. This article differs from the Liu and Forker study because it formally and empirically compares the supply response to a shift in demand under both the rational- and naive-expectations assumptions.

I have estimated a pair of supply functions by solving or partially solving an explicit dynamic optimization problem. One result is a rational-expectations supply function and another is a naive- or static-expectations supply function. The coefficients of the rational-expectations supply function depend on production and technology parameters of representative firms, and on parameters defining the movement of input prices and market-level demand shifts. For the purposes of this discussion, the former set of parameters consists of structural parameters; the latter set consists of state parameters. Production and technology parameters are structural because they describe a production process of firms that is invariant to changes in the conditions of the market. Shifts in consumer preferences do not alter the production process of farm firms. On the other hand, state parameters define the movement (or the distribution) of the state variables of the problem: shifts in demand and input prices. The aggregate supply response of milk-producing firms does not alter the distribution of these state variables. Under the rational-expectations hypothesis, the distribution of both demand shifts and input prices and the specification of the objective functions of firms induce a distribution of (endogenous) milk prices and supply of milk. This distribution defines the conditional, mathematical expectation of milk price and aggregate supply. Changes in the distribution of state variables alter the mathematical or rational expectation of milk price and aggregate supply (which in turn affect supply). Separating state parameters from structural parameters is essential under the rational-expectations paradigm if changes in supply due to systematic changes in state variables are to be correctly evaluated. The naive-expectations assumption breaks the link between the distribution of state variables and milk supply. Under the naive-expectations paradigm, a separation of state and structural parameters is unnecessary.

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[1]Sources are listed in the references section at the end of this article.

Under the rational-expectations assumption, state variables are characterized as being generated from permanent or transitory shocks or disturbances. Suppose a growth hormone alters the taste of dairy products, but otherwise leaves the production process unchanged. If this shock alters the demand shifter for protracted periods, the shock is said to be permanent. If it shifts demand for only a short period, the shock is transitory. The different distributions of the demand shifter imply different distributions of the farm price of milk, different expected milk prices, and hence a different supply function. To assess how the supply function will change when consumer tastes change, it is necessary to separate structural from state parameters. The econometric problem of separating these two sets of parameters is termed the identification problem. Successfully separating structural and state parameters results in a model of a market in which suppliers make no systematic errors in prediction.

The identification problem does not arise under the naive-expectations paradigm. The reason is that a change in the distribution of the demand shifter in no way alters the fixed and assumed distribution of milk prices. Under naive expectations, only changes in the structural parameters (for example, a change in the production process) can alter a naive supply function, so that identifying state and structural parameters is unnecessary. On the other hand, invoking the naive-expectations assumption virtually ensures that agents *make* systematic errors in prediction.

Dynamic Optimization in Agricultural Economics

Agricultural economists see dynamic optimization techniques as a means of uncovering the underlying structure of dynamic reduced-form econometric models (for example, Wohlgenant, 1985; Eckstein, 1985; Lopez, 1985; Holt and Johnson, 1989). Studies appealing to dynamic duality and static expectations deliver reduced-form models with well-defined restrictions on their coefficients as do studies appealing to stochastic dynamic programming and rational expectations. While both sets of restrictions are defined at least partly in terms of the structural parameters, the restrictions are usually different.

Two main strategies exist for estimating the structural parameters of a dynamic optimization problem using time-series data. One strategy involves solving for the unobserved expectation of a relevant variable in terms of observed variables and substituting the solution for the unobserved variable. In this substitution approach, the parameters of the reduced-form solution are explicit nonlinear functions of the state and structural parameters. Wohlgenant and Eckstein (1984) employed this substitution method when invoking the rational-expectations hypothesis. Lopez employed the substitution method when invoking the static- or naive-expectations hypothesis. Because the nonlinear restrictions on the parameters of a rational-expectations reduced form are complex, the substitution method seems limited to small-scale dynamic optimization problems.

The other strategy involves direct estimation of structural parameters by replacing unobserved expectations of a variable with the observed variable. The resulting errors-in-variable estimate is attractive because it can be computed even for large-scale models. Weersink and Tauer (1990) follow this estimation strategy, invoke static expectations, and compute reduced-form elasticities of regional milk supply from the structural parameter estimates. Antle (1987) gives a classic argument for an errors-in-variable estimate under rational expectations: in cases in which a rational-expectations equilibrium cannot be found, structural parameters of the model are obtained from the first-order conditions of firms.

Regardless of which strategy the analyst chooses, the parameter estimates of a dynamic optimization problem must imply a reduced-form solution. In the analysis below, a reduced-form solution obtains only if the parameter estimates satisfy the inequality restrictions sufficient for a solution. In this paper, these restrictions are placed on the parameter estimates.

The estimation approach in this report combines the substitution and the errors-in-variables approaches (see Tauchen, 1986; Boos and Monahan, 1986; and Kling and Sexton, 1990). Estimated from this combined approach are closed-form, ex-post rational- and naive-expectations milk supply functions. Because modeling the U.S. Dairy Support Price program prohibits a closed-form rational solution (Holt and Johnson, 1989), the program is ignored. Nevertheless, the closed forms illustrate the fundamental difference between the paradigms: static (naive) supply functions are invariant to systematic changes in the demand shifter, whereas rational-supply functions are not. Econometric estimates are used to assess how the rational-expectations supply response changes when demand shifts change from permanent to transitory.

Economic Model

The properties of milk supply under rational or naive expectations are established from a full or partial solution to a dynamic social welfare problem of

the dairy industry. In the following problem, the producer begins each period with a given stock of milk-producing animals and must decide on the number of replacement heifers to add to the herd next period. The structural economy consists of the parameters of the representative farm firm's dynamic objective function and the parameters of the derived demand for farmer's milk. The model is closed with an expectation assumption. For the rational-expectation assumption, closure entails the specification of an information set and a description of the difference equations describing the movements of cow prices, cull cow prices, and the demand shifter. Again, the analysis ignores the endogenous features of the dairy support program so as to attain closed-form rational-supply solutions. (See notations and definitions in table 1.)

Consider the optimization problem facing each farm firm in a competitive dairy economy. In particular, each firm chooses $\{k_t\}$, the sequence of the firm's stock of milk-producing cows to maximize the expected, discounted future value of the firm, defined as:

$$\max E_0 \Sigma_{t=0}^{\infty} \beta^t \Pi_t, \tag{1}$$

where:

$$\Pi_t = fk_t p_t - (J_t - \beta J_{t+1})\, k_t + c_t \sigma k_t - (1/2)\, hk_t^2 - (1/2)\, dr_t^2, \tag{2}$$

subject to:

$$k_t = (1-\sigma)\, k_{t-1} + r_t \qquad \textit{(equation of motion)} \tag{3}$$

$$p_t = a_0 - a_1 f K_t + z_{t-1} \qquad \textit{(derived demand for farm milk)} \tag{4}$$

$$J_{t+1} = b_0 + b_1 + J_t + \epsilon_{1t+1} \qquad \textit{(cow price)} \tag{5}$$

$$c_{t+1} = b_2 + b_3 c_t + \epsilon_{2,t+1} \qquad \textit{(cow cull price)} \tag{6}$$

$$z_{t+1} = b_4 + b_5 z_t + \epsilon_{3,t+1} \qquad \textit{(demand shifter)}. \tag{7}$$

As each quarter t begins, the representative farmer knows the blend price of milk (p_t), the price of cows (J_t), the price of culled cows (c_t), and the firm's and economy's beginning period stock of milk-producing animals (k_{t-1} and K_{t-1}). The firm's problem is to choose the current period's herd size. Last period's demand shifter (z_{t-1}) partly determines the current milk price, a feature consistent with the Federal Milk Marketing Orders valuing milk according to formulas incorporating market conditions for manufacturing milk in Minnesota and Wisconsin. The information available to the milk producer at the beginning of the period is summarized in an information set:

Table 1—Notations and definitions

t:	integer denoting a discrete time interval (quarter)
k_t:	the firm's stock of milk-producing animals at the end of period t
K_t:	the economywide stock of milk-producing animals at the end of period t
r_t:	replacement heifers that have entered the herd during period t
p_t:	the blend price of milk received by the farmer in period t
J_t:	the price of milk-producing animals received in period t
c_t:	the cull cow price received in period t
z_t:	a demand shifter in period t
β:	a discount factor
σ:	a parametric slaughter rate
f:	a milk-yield parameter
h:	capital cost associated with milk-producing cows
d:	capital cost associated with replacements
E_t:	a mathematical-expectations operator conditioned on the information set available at the beginning of period t
$\epsilon_{1,t+1}, \epsilon_{2,t+1}$, and $\epsilon_{3,t}$:	three white noise error terms, each of which is uncorrelated with all elements of the information set available at the beginning of period t

$$\Omega_t = \{\ldots, p_{t-1}, p_t; \ldots, z_{t-2}, z_{t-1}; \ldots, J_{t-1}, J_t; \ldots, c_{t-1}, c_t; \ldots, k_{t-2}, k_{t-1}, \ldots, K_{t-2}, K_{t-1}, \ldots\}. \tag{8}$$

When period t begins, the representative producer decides on the herd size by adding replacement heifers and culling cows. The farmer receives milk revenues of the amount $p_t f k_t$ for milk produced in period t and receives a return of the amount $c_t \sigma k_t$ for culled animals during period t. The cull rate, σ, is assumed fixed so a fixed proportion of the herd size is culled each time period. The unit opportunity cost of employing a mature animal in milk production in period t is the rental rate, w_t, of beef animals, where $w_t = J_t - \beta E_t J_{t+1}$, and J_t is the price of beef animals. Denote q as a rental rate of capital fixed over all periods of the optimization problem. Then, $\frac{1}{2} qh^2 k_t$ denotes the capital costs of holding and maintaining the stock of mature animals, and $\frac{1}{2} qd^2 r_t^2$ represents the capital costs of holding and raising replacement heifers. Dividing the value function by q delivers the above optimization problem with prices normalized by the price of capital (Townsend, 1983).

Each firm in the economy satisfies the Euler equation:

$$E_t\{fp_t - J_t + \beta J_{t+1} + \sigma c_t - [h+d+\beta d(1-\sigma)^2]\, kt + d(1-\sigma)\, k_{t-1} + d(1-\sigma)\, \beta k_{t+1}\} = 0, \tag{9}$$

for t = 0, 1,.... The left-hand side of equation 9 is the derivative of equation 1 with respect to k_t. The first term is the marginal revenue product, the second and third terms represent the marginal (opportunity) cost of using animals for milk production, and the fourth is the marginal return from slaughter. The remaining three terms are actually the sum of two terms: $-\{h\ k_t + d[k_t - (1-\sigma)\ k_{t-1}]\}$ and $\beta d(1-\sigma)\ \{k_{t+1} - (1-\sigma)\ k_t\}$. The first term is the total marginal capital cost of holding current-period cows and current-period replacements. The second term states that as the herd size increases during the current period, the next period's replacements fall. The second term reflects the next period's savings (in present dollars) due to the current period's decision.

Consider a demand expansion resulting from a shift in demand, so the marginal revenue product rises. What happens to herd size and milk supply? The answer rests on two comparative dynamic results stated in the following two propositions (see proofs in appendix A):

Proposition 1: As the parameter d in equation 2 increases, the response of farm firms to a change in the price of milk decreases. **Proposition 2:** The more permanent the shift in demand, the larger the response of farm firms to the shift in demand.

Proposition 1 states that the speed at which firms respond to an effective change in the price of milk slows as the marginal cost of holding and raising replacement heifers increases, regardless of the particular expectation assumption. Proposition 2 applies only to a rational-expectations solution. Before elaborating on proposition 2, it is necessary to define a permanent shift in demand as well as the concept of a systematic change in the demand shifter.

Equation 7 is a first-order Markov process describing realizations of the demand shifter, z_t. Specifically, equation 7 indicates that a realization of z is composed partly of a fundamental disturbance term (one that is uncorrelated with past z and serially uncorrelated with itself) and a one-period lagged realization of z. Equation 7 could be "inverted" to express each current realization of z as a function of an infinite weighted sum of the present and past disturbance terms. This inversion defines how long a single shock or disturbance translates into changes in realizations of the demand shifter. The state parameter b_5 completely describes the movement of the demand shifter (it defines its mean, variance, and serial covariance). The closer the absolute value of b_5 is to unity, the longer a single shock affects future realizations of the demand shifter, that is, the more permanent is the effect of a shock on demand. The closer the absolute value of b_5 is to zero, however, the more short-lived the effect, making the demand shift transitory.

Proposition 2 states that the more permanent the shift in demand, the greater the current period response to the demand shifter. The implications of proposition 2 are clear. If the shift in demand is permanent, a continued rise in milk price can be predicted. Rational firms will expand beyond the amount justified by the increase in the marginal revenue product alone. On the other hand, if the demand shift is transitory, prices will fall in the next period, and firms may plan to contract, dampening the expansion implied by the increase in the marginal revenue product alone.

According to proposition 2, the rational supply response to a demand shifter cannot be understood unless the movement of the demand shifter is understood. A systematic change in the demand shifter, due to a change in advertisement, for example, might transform a transitory demand shifter into a permanent demand shifter. Proposition 2 states that such a change would induce a larger supply response.

Both propositions imply that a rational-expectations milk supply function depends not only on the technology of firms in the economy but also on the distribution of the demand shifter.

The technology parameters of representative firms are contained in equation 9. Since equation 9 is linear in variables, it can be aggregated exactly to the market level. Hence, the technology parameters of the problem might be estimated using aggregate time series data and an aggregated version of equation 9. The obstacle to estimation, however, is that equation 9 is unobservable because of the presence of the expectations operator. However, writing equation 9 compactly as:

$$E_t F_t(\Theta) = 0, \tag{10}$$

where $\Theta = [\beta,f,\sigma,h,d]'$, and noting that for any mathematical expectation, $F_t(\Theta) = E_t F_t(\Theta) + u_t$, according to equation 10:

$$F_t(\Theta) = u_t. \tag{11}$$

Since equation 10 contains unobservable data, its parameters cannot be estimated from time series data. On the other hand, parameter estimates of equation 11 can be obtained by appealing to the rational-expectations hypothesis.

Given the information set Ω_t, the correlation between u_t and more than one variable of $F_t(\Theta)$ can-

not be ruled out, so equation 11 violates a regression structure. The rational-expectations hypothesis provides a set of orthogonality conditions that are exploited in estimation: $Eu_t \mid \Omega_t = 0$. These conditions imply that if one forms an instrument vector, I_t, with elements of Ω_t, $Eu_t \otimes I_t = 0$ (where $\otimes$ denotes Kronecker product, and E is the unconditional expectation). However, the specification of the information set implies the serial correlation of these moment error terms cannot be ruled out. The Generalized Method of Moments (GMM) estimate of Θ is denoted as $\Theta^{\#}$. The GMM estimator exploits the orthogonality conditions of the model and accounts for serial correlation of the moment error terms. Since $\Theta^{\#}$ minimizes a well-defined objective function of the data sample, the important point for what follows is that $\Theta^{\#}$ is a statistic of the sample. (See Gallant, 1987, chapter 7, for a more detailed description of the GMM estimator.)

The final component of the structural model involves the slope parameter of the derived demand for producer milk. Wohlgenant and Haidacher have rigorously estimated pairs of static derived demand functions by accommodating general equilibrium effects of a price change from retail to farm. Wohlgenant and Haidacher's pairs of functions take the form $\log P = A_0 - A_1 \log Q + \log Z$, where P is retail or farm-level price, Q is farm output, and Z represents marketing costs, demand shifters, and trend. The coefficients of this pair of double-log specifications are flexibility estimates. Wohlgenant and Haidacher obtain a point estimate of 1.493 on the A_1 coefficient of the dairy farm price equation.

Multiplying this number by the mean of the ratio of prices to milk supply gives 1.130, the value assigned to the demand slope parameter, a_1, in equation 4.

The remaining task is to estimate the structural and state parameters of the above model and solve for reduced-form supply functions under two different expectations schemes.

Methodology

Equations 1-7 pose a dynamic, stochastic programming problem, the solution of which is a rational-expectations competitive equilibrium. If sufficient conditions (stated below) for an optimization are satisfied, the herd size that solves this dynamic programming problem is:

$$k_t = \psi_1 k_{t-1} + \psi_2 + \psi_3 J_t + \psi_4 c_t + \psi_5 z_{t-1}. \qquad (12)$$

Equation 12 is the stochastic equation of motion of cow numbers. It is the rational-expectations solution, and solves equations 1-7. The coefficients of equation 12 optimally combine the distributions of cow price, cull price, and the demand shifter with the technology parameters of representative firms. The ψ_i of equation 12 are nonlinear functions of the structural and state parameters of the problem. Equation 12 is used to compute the rational-expectations ex-post supply function:

$$M_t = \lambda M_{t-1} + \kappa_1 + \kappa_2 J_t + \kappa_3 c_t + \kappa_4 z_{t-1} + \alpha_1 p_t. \qquad (13)$$

The computation of equation 13 from the equation of motion of cow numbers (see Sargent, 1987(b), chapter 14) ensures that the expected future discounted stream of output price is consistent with the expectation of output price implied by the demand function for producer milk. The expected future discounted streams of cow prices, cull prices, and the demand shifter are consistent with the vector autoregression given by equations 4-6.

I used the same estimates of the structural parameters, Θ, and the assumption of static expectations to compute a different equation of motion of herd size. This equation of motion solves the dynamic problem specified only by equations 1-3, and so ignores the milk demand equation and the specification of the cow price, cull price, and the demand shifter. The solution ensures the expected future discounted stream of any price is consistent with the static-expectations scheme of Chambers and Lopez: if $\{x_t\}$ is any sequence, then $E_t X_{t+j} = x_t$ (for $j \geqslant 0$) is its static expectation. By multiplying the static-expectations solution by the parameter f, the milk supply function is:

$$M_t = \lambda M_{t-1} + \delta_2 J_t + \delta_3 c_t + \alpha_2 p_t, \qquad (14)$$

which resembles the supply function specified by Liu and Forker.

The pair of supply functions presented above are similar in that the λ coefficient is shared by both equations. A shared λ coefficient stems from the assumption that the technology of firms is invariant to the expectation assumption. The remaining coefficients of the supply functions differ. These differences are due solely to the expectation assumption: most notably, the static-expectations supply response to a demand shift is zero; the rational-expectations supply response to a demand shift is nonzero.

Conditions sufficient to ensure a rational-expectations solution given by equation 12 (and, hence, ensure the computation of equation 13) are (Sargent, 1987b, chapter 1):

$$\{a_1 f^2 + d + h\} > 0. \qquad (15)$$

$$d(1-\sigma)^2\{1 - \frac{d}{a_1 f^2 + d + h}\} \geqslant 0. \qquad (16)$$

$|b_1|, |b_2|, |b_5| < \beta^{-1/2}$ (see equations 5, 6, 7). (17)

Equations 15 and 16 with $a_1 f^2 = 0$ are sufficient conditions to compute the static-expectations supply function given by equation 14.

A bootstrap procedure provides estimates of the structural, vector autoregression, and reduced-form supply parameters of the study that satisfy conditions 15-17. A similar procedure was applied by Kling and Sexton (1990) in a static demand model. Tauchen (1986) illustrated how to bootstrap a nonlinear, continuous-time, dynamic, and stochastic programming problem. Parameter estimates are robust because the procedure imposes no distribution on the likelihood of the model.

A seemingly unrelated and unrestricted linear system of regressions generates bootstrap samples of the herd size, cow prices, cull prices, and the demand shifter (appendix B). This regression model consists of an equation of motion for cow numbers similar to equation 12 with no cross-equation restrictions, and an appended disturbance term. Equations 5, 6, and 7 also constitute the regression system. The farm price of milk is generated using the demand function defined by equation 4 and the definition of the demand shifter (appendix C). For each set of bootstrap samples, GMM estimates of the parameters h and d of the firms' objective functions are computed. If parameters h and d and the parameters of equations 5-7 satisfy the sufficient conditions for a rational-expectations equilibrium given by equations 15-17, the longrun expected supply elasticity and the coefficients of the rational- and static-expectations supply functions are computed. If the parameters do not satisfy the sufficient conditions, another bootstrap sample is drawn. The probability that the conditions for a rational-expectations solution are satisfied is computed from the number of bootstrap samples for which the conditions given by equations 15-17 hold, divided by the number of bootstrap samples drawn. Appendix B furnishes more details of this procedure.

Results

Table 2 reports the means and standard deviations (in parentheses) of the bootstrap distribution of parameter estimates that satisfy equations 15-17. The first equation represents the unrestricted (that is, no cross-equation restrictions) cow number equation, and the next three equations represent the stochastic-difference equations governing the cow price, the cow cull price, and the demand shifter variables. Next, table 2 reports the bootstrap estimate of the h and d parameters of the Euler equations and a longrun expected supply elasticity of 1.2 for the U.S. dairy industry. The final two equations represent the estimated milk supply functions with all of the cross-equation restrictions implied by the rational- and naive-expectations schemes.[2]

The results highlight the notion that supply response critically depends on the assumption of expectations. For example, the shortrun rational-expectations supply elasticity with respect to the blend price of milk is approximately 0.06, while the shortrun naive-expectations supply elasticity with respect to the blend price of milk is approximately 0.10.

The variable sequence of interest in this study is the demand shift sequence. Table 2 shows an estimate of 0.993 for the coefficient on the lagged demand shifter in the demand shift equation, that is, b_5 in equation 7. The magnitude of this estimate implies that historical shifts in the total demand for milk within the U.S. dairy industry have been permanent, which is not surprising given the nature of regulations over this period. The static-expectations response to a demand shift is zero because the static expectation of the price of milk ignores the demand function. The rational-expectations response to a one-period-lagged demand shift is 0.1712, and implies milk supply increases of 0.16 percent for each 1-percent increase in the demand shifter. The estimated standard error associated with this estimated coefficient indicates that the supply response to lagged demand shifts is computed no less precisely than most of the other responses.

I now show how empirical estimates of the supply functions differ under the two expectations schemes, and the manner in which a systematic change in the demand shifter affects supply response. Because the point estimates reported in table 2 satisfy conditions 15-17, I was able to compute both a rational- and a naive-expectations supply function from the point estimates. The rational-expectations supply function evaluated at the point estimate is:[3] $M_t = .8416\ M_{t-1} - .0031 - .3762\ J_t + .1188\ c_t + .1987\ z_{t-1} + .0789\ p_t$, and the naive-expectations supply function evaluated at the point

[2]The data sources, the transformations, and the sample means are reported in appendix C.

[3]The supply functions computed at the point estimates reported in table 2 differ from the supply functions reported at the bottom of table 2 because the parameters of supply are nonlinear functions of the parameters in a firm's objective function (for example, h and d) and the parameters of the vector autoregression describing cow prices, cull prices, and the demand shifter.

Table 2—Estimation results

Bootstrapped seemingly unrelated regressions:					
k_t	$= 0.9880\ k_{t-1}$	$-\ 0.0082$	$-\ 0.0524\ J_t$	$+\ 0.0349\ c_t$	$+\ 0.0320\ z_{t-1}$
	(.008)	(.014)	(.009)	(.007)	(.004)
J_{t+1}	$= 0.0379$	$+\ 0.9530\ J_t$			
	(.018)	(.025)			
c_{t+1}	$= 0.0477$	$+\ 0.9419\ c_t$			
	(.009)	(.007)			
z_t	$= 0.0155$	$+\ 0.9929\ z_{t-1}$			
	(.0116)	(.0124)			
Euler equation:					
	h	d			
	0.0923	3.4279			
	(.038)	(3.779)			
Longrun expected supply elasticity:					
	1.210				
	(.549)				
Probability restrictions hold:					
	0.421				
Milk supply, rational expectations:					
M_t	$= 0.7596\ M_{t-1}$	$-\ 0.0025$	$-\ 0.3784\ J_t$	$+\ 0.1098\ c_t$	$+\ 0.1712\ z_{t-1}$
	(.145)	(.006)	(.017)	(.017)	+ (.095)
	$+\ 0.0692\ p_t$				
	(.039)				
Milk supply, naive expectations:					
M_t	$= 0.7596\ M_{t-1}$	$-\ 0.0323\ J_t$	$+\ 0.0453\ c_t$	$+\ 0.1164\ p_t$	
	(.145)	(.018)	(.025)	(.065)	

estimate is: $M_t = .8416\ M_{t-1} - .0378 - .0529\ J_t + .1360\ p_t$.

The response coefficient on the lagged demand shifter in the rational-expectations supply function (0.1987) implies that for a 1-percent increase in the previous period's shift in demand, milk supply increases about 0.19 percent. As stated above, the coefficient of 0.9929 on the lagged demand shifter equation describes a permanent demand shift sequence. The important point for economic analysis, however, is that under rational expectations, the supply response to a shift in demand depends on the distribution of the shift in demand. If the shifts become less permanent (more transitory), the rational-expectations supply function will change, and, in accordance with proposition 2, the supply response to shifts in demand will diminish. Under static expectations, the supply response to changes in demand shifts remain zero regardless of how the shifts change.

Table 3 displays the relationship of supply response to a permanent and a transitory demand shifter under rational and naive expectations. Under rational expectations, a diminished supply response occurs as the demand shift sequence becomes less permanent. A supply coefficient (top line) is associated with an almost purely permanent demand shifter, while the bottom line reports a supply coefficient associated with an almost purely transitory demand shifter. If firms see the current increase in demand as permanent, milk prices will be expected to continue to increase and firms will expand milk herds. If a current increase in demand is viewed as transitory, however, milk prices will be expected to fall in the next period, and firms will dampen any current-period expansion. The difference in supply response between an almost purely permanent de-

Table 3—Milk supply response to the lagged demand shifter under different distributions of the demand shifter, with rational and naive expectations

Coefficient on the demand shifter in the demand shifter equation (b_5)[1]	Supply response coefficient to lagged demand shift	
	Rational[2] (κ_4)	Naive
0.992920	0.198687	0
.496460	.123367	0
.248230	.112739	0
.124115	.109128	0
.062057	.107597	0

[1]The value reported is the b_5 coefficient from equation 7.
[2]The value reported is κ_4 from equation 13.

mand shifter and an almost purely transitory demand shifter is almost 50 percent. Under the static-expectations assumption, firms do not respond to changes in the movement of the shift in demand.

The naive-expectations paradigm exploits the artificial separation of supply and demand, a separation legitimately appealed to in static models. The rational-expectations paradigm, on the other hand, states that demand and supply cannot be treated independently because the demand function contains information regarding the price of milk.

Conclusions

Reduced-form supply functions fully derived in a dynamic optimization context change when consumer demand for milk systematically changes. Supply is altered despite a fixed structural economy. Changes in supply are not evident when agents are assumed to ignore systematic changes in the demand shifter, as is the case under the static-expectations assumption. This point is a general one, but is often ignored in large-scale econometric modeling. Perhaps the reason is convenience: the cumbersome identification problems associated with the estimation of a rational-expectations model might seem forbidding. However, as the methodology in this article and elsewhere (Tauchen, for example) illustrates, techniques are currently available to estimate and solve dynamic and stochastic optimization models of greater complexity than the one I have presented.

The comparison of expectation paradigms has little to do with the comparison of the forecasting record of either reduced form. It is difficult to judge the forecasting ability of each of the two estimated supply functions. Some analysts argue that permitting individual agents to alter supply decisions in the face of systematic changes in their environment is fundamental to the usefulness of a model as a policy tool (Lucas, 1976, 1982). The consequence of allowing individual agents to alter supply decisions in the face of a systematic change in their environment is also illustrated by the results.

For analysts intent on measuring the response of the dairy economy to a shift in demand, it seems prudent to carefully consider the expectations of agents whose behavior is assumed to be embedded in the model. In particular, the results suggest that a persistent demand shift may have a different effect on milk supply than will a transistory demand shift of the same magnitude. The results of this relatively simply model suggest the difference is significant under the rational-expectations assumption and nonexistent under the naive-expectations assumption. Work that considers the effect of the support price program on agents' expectations, for example, will undoubtedly alter the magnitude of this effect.

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Appendix A—Proving Propositions 1 and 2

This appendix provides the proof of propositions 1 and 2. **Proposition 1:** As the parameter d in equation 2 increases, the response of farm firms to a change in the price of milk decreases.

Proof: Note the firm's Euler equations are represented as:

$$E_t\{\beta k_{t+1} + \varphi k_t + k_{t-1}\} = \frac{1}{d(1-\sigma)} E_t$$

$$\{-fp_t + (J_{t+1}\beta J_{t+1}) - \sigma c_t\}, \qquad \text{(A1)}$$

where,

$$\varphi = -\{\frac{\beta d(1-\sigma)^2 + d+h}{d(1-\sigma)}\},$$

or as in Sargent (1987, chapter 14):

$$(1-\lambda L)\, k_t = \frac{\lambda}{d(1-\sigma)} E_t \Sigma_{i=0}^{\infty} (\beta\lambda)^1 \{fp_{t+1}$$

$$- (J_{t+1} - \beta J_{t+1+i}) + \sigma c_{t+i}\}, \qquad \text{(A2)}$$

where,

$$\lambda = \frac{-\varphi-(\varphi^2-4\beta)^{1/2}}{2\beta},$$

and the term in brackets on the right-hand side of equation A2 is the effective milk price. According to the arguments given by Sargent (1987(b), chapter 8):

$$0 < \lambda < \beta^{-1/2}.$$

Setting i = 0, and taking the partial derivative of k_t with respect to the term in brackets gives:

$$\frac{\partial}{\partial\{\cdot\}} k_t = \frac{1}{(1-\sigma)} \cdot \frac{\lambda}{d} > 0.$$

The inequality holds because equations 15 and 16 in the text imply d > 0. Given the sign of this partial, it suffices to prove:

$$d\,(\frac{\partial\lambda}{\partial d}) - \lambda < 0. \qquad \text{(A3)}$$

Using the above definitions, equation A3 can be rewritten as:

$\{1/(2\beta)\,(1/(\varphi^2-4\beta)^{1/2})\} \cdot \{\varphi + (\varphi^2-4\beta)^{-(1/2)}\}$

$$\cdot \{1/(2\beta)\} \cdot \{(\varphi^2-4\beta)^{(1/2)} - \frac{h}{d(1-\sigma)}\} < 0. \qquad \text{(A4)}$$

By virtue of the fact that λ is real, the first term in { } of equation A4 is positive. Since $\varphi < 0$, the second { } term is negative, and since $0 < \beta < 1$, the third { } term is positive. Hence, the proof of equation A3 or A4 amounts to the proof of:

$$(\varphi^2 - 4\beta)^{(1/2)} - \frac{h}{d(1-\sigma)} > 0, \qquad \text{(A5)}$$

Or, given definitions of φ and λ, the proof of:

$$\frac{\beta d(1-\sigma)^2 + d}{d(1-\sigma)} - 2\beta\lambda > 0. \qquad \text{(A6)}$$

To prove equation A6, note that $\max(\lambda) = \beta^{-1/2}$. This follows from the fact that λ is the inverse root of the characteristic equation formed by the left-hand side of equation A1. Satisfaction of the sufficient conditions given by equations 15 and 16 in the text ensure that the roots of this characteristic equation are not less than $\beta^{1/2}$ in modulus. Thus $\max(\lambda) = \beta^{-1/2}$, and:

$$\frac{\beta d(1-\sigma)^2 + d}{d(1-\sigma)} - 2\beta\lambda > \frac{\beta d(1-\sigma)^2 + d}{d(1-\sigma)} - 2\beta^{1/2}$$

$$= \frac{\beta(1-\sigma)^2 + 1-2\beta^{1/2}(1-\sigma)}{1-\sigma}$$

$$> \beta(1-\sigma)^2 + 1-2\beta^{1/2}(1-\sigma) > 0. \qquad \text{(A7)}$$

The last inequality holds because $0 < \beta(1-\sigma)^2 < 1$. Q.E.D.

Proposition 2: The more permanent the shift in demand, the larger the response of farm firms to the shift in demand.

Proof: Proposition 2 states that as the demand shift becomes more permanent, (as $|b_5|$ becomes larger), the economywide response to the demand shifter becomes larger. Analogous to equation A2, the economywide solution satisfies:

$$(1-\omega L)k_t = \frac{\omega}{d(1-\sigma)} E_t \Sigma_{i=0}^{\infty} (\beta\omega)^i \{f z_{t+i-1}$$

$$- (J_{t+i} - \beta J_{t+1+i}) + \sigma c_{t+i}\}, \qquad \text{(A8)}$$

where,

$$\omega = \frac{-\delta-(\delta^2-4\beta)^{1/2}}{2\beta},$$

and,

$$\delta = \frac{-\beta f^2 a_1}{d(1-\sigma)} + \varphi.$$

Proposition 2 requires the computation of:

$$E_t\Sigma_{i=0}^{\infty} (\beta\omega)^i z_{t+i-1}. \qquad \text{(A9)}$$

By the multivariate Weiner-Kolmogorov formulas (Sargent, 1987(b), chapter 11), equation A9 is evaluated as:

$$\{\frac{1}{1-\beta\lambda b_5}\} z_{t-1}.$$

Proposition 2 states:

$$\frac{\partial}{\partial b_5} \{\frac{1}{1-\beta\lambda b_5}\} > 0,$$

which is easily verified.

Appendix B—Computing the Estimates

This appendix details how the restricted bootstrap estimates are computed. The inequality-restricted bootstrap estimates and standard errors are computed through the following eight steps:

(i) Compute seemingly unrelated, unrestricted estimates of equation 12. That is, compute estimates of the ρ_i in the model:

$$k_t = \rho_1 k_{t-1} + \rho_2 + \rho_3 J_t + \rho_4 c_t + \rho_5 z_{t-1} + u_{1t}$$
$$J_{t+1} = \rho_6 + \rho_7 J_t + u_{2t+1}$$
$$c_{t+1} = \rho_8 + \rho_9 c_t + u_{3t+1}$$
$$z_t = \rho_{10} + \rho_{11} z_{t-1} + u_{4t}.$$

The ρ_i are free parameters, as they contain no restrictions implied by economic theory.

(ii) Compute the 1-by-4 row vector of regression residuals, $u_s = [u_{1s}, u_{2s+1}, u_{3s+1}, u_{4s}]$, $s+1 = 2,\ldots,T$ (where T is the terminal period of the data sequence) from the data and the original seemingly unrelated estimates of the ρ_i. Stack each row vector and use the residuals to create the empirical distribution function, with each 1-by-4 row vector having probability mass 1/(T-1). Label the (T-1)-by-4 matrix of residuals $\epsilon^{\#}$.

(iii) Resample from rows of $\epsilon^{\#}$ with replacement and construct the kth sample sequence of length T-1 of output prices $\{p_t^*\}^{(k)}$, cow numbers $\{k_t^*\}^{(k)}$, beef prices $\{J_{t+1}^*\}^{(k)}$, cull prices $\{c_{t+1}^*\}^{(k)}$, and the demand shifter $\{z_t^*\}^{(k)}$, using estimates computed in step i and the demand function specified in equation 4. Use

the kth sample sequences to compute seemingly unrelated estimates of the (free) ρ_i parameters in step i. Label the vector of estimates $\rho^{\#}_{k}$.

(iv) Check the stability conditions (for example, equation 17) of the beef price, cull price, and demand shifter equations using appropriate elements of $\rho^{\#}_{k}$. If the three conditions hold, proceed to step v. If not, return to step iii.

(v) Compute a Generalized Method of Moments estimator of Θ in the model specified by equations 9 and 11 from the kth sample sequences generated in step iii. In the estimation, β, f, and σ are set to 0.95, 0.18, and 0.07, so $\Theta = [0.95,0.18,0.07,h,d]'$; and $[1,J_{t-1},p_{t-1},k_{t-1}]'$ represents the instrumental variable vector. Label the parameter estimates of the Euler equation $\Theta_k{}^{\#*}$.

(vi) If $\Theta_k{}^{\#*}$ satisfies conditions 15 and 16 (and since the coefficients, $\rho^{\#}_{i,k}$, associated with the state variables satisfy stability), the kth draw is successful. Compute the rational- and static-expectations supply functions using $\Theta_k{}^{\#*}$, a_1, the parameters of the cow price, cull price, and demand shifter equations. If $\Theta_k{}^{\#*}$ fails to satisfy equations 14 and 15, return to step iii.

(vii) If the number of draws is less than the prescribed number, go to step i. Otherwise proceed.

(viii) Compute the means and variances of the successful parameter estimates in the usual way. The mean minimizes a quadratic loss function and represents a restricted estimate. Construct the standard derivation from the variance estimate.

Appendix C—Data and Description, Transformations, and Fixed Parameters Estimates

Variables used in the study are constructed from data found in various Dairy Situation and Outlook reports and an ERS database. The fundamental data sequences are of length 120, being defined over 1960-89. Each series is normalized by the 1982 average, so each variable is an index (1982 = 1.0). The mean is reported in parentheses following the definition.

(M) = milk production, United States, 50 States (0.94)
(J) = beef cattle prices received by farmers (0.70)
(c) = cull cow prices received by farmers (0.73)
(K) = milk cows on farms (1.12)
(p) = producer price, all milk wholesale, at average test (0.65)
(z) = demand shifter, $z_{t-1} \equiv p_t + (1.13)(0.18)K_t$ (0.88)

Setting $\beta = 0.95$ corresponds to an interest rate of approximately 5 percent. $\sigma = 0.07$ is based on a USDA-estimated annual slaughter rate of 28 percent. f = 0.18 is the coefficient obtained from a regression of fourth differences of milk supply on fourth differences of cow numbers over the historical period.

State-Level Output Supply and Input Demand Elasticities for Agricultural Commodities

Pedro A. Villezca-Becerra and C. Richard Shumway

Abstract. *Own- and cross-price production elasticities, estimated in four major agricultural States (California, Iowa, Texas, and Florida), measure the sensitivity to price changes of as many as 25 individual crop and livestock output supplies and six input demands. While most responses were highly inelastic, a wide range of elasticities occurred across States. The range was generally greater for crop supplies than for livestock supplies or input demands. The wide range of elasticities demonstrates the need for economic analysis to focus on specific groups of producers when assessing distributional consequences of policy changes.*

Keywords. *Demand, elasticity, multistage, State, supply.*

Domestic and international policy simulations require estimates of agricultural output supply and input demand relationships. For example, successful GATT negotiations hinge on how producers in the United States and elsewhere respond to changes in market prices and withdrawal of output- and input-distorting government incentives. The relative merits of alternative environmental policies depend on producers' input choices. Secondary (or indirect) effects on outputs or inputs other than the one(s) directly targeted by a particular policy instrument are sometimes as great as the direct effects. How producers are affected can vary with scale of operation, resources, and geographic location. Understanding intercommodity and distributional consequences demands reliable estimates of own- and cross-price commodity supplies and input demands for important groups of producers.

Yet, because of computational burden and data limitations, empirical research on intercommodity relationships has generally concentrated on estimates at a national or regional level for highly aggregated categories (Ball, 1988; Huffman and Evenson, 1989; Shumway and Alexander, 1988).[1] Policy inferences from such studies have been limited to the aggregate effects of agricultural policies, often ignoring geographic and commodity distributional effects.

Because of the large number of agricultural commodities produced and inputs used and because of the heterogeneity of production in most areas of the country, complete output supply and input demand elasticity matrices can be derived only if estimation models can be simplified. Simplification in model specification becomes necessary to conserve degrees of freedom in estimation and to reduce collinearity. Analytic simplification is justifiable whenever data are consistent with certain theoretical and structural properties. For example, when production is nonjoint in inputs, commodity supplies are independent of other output prices. When production is separable, quantities can be aggregated and production analysis can be performed in stages with subsets of variables and with the aggregates without distorting the disaggregated results. Separability is particularly crucial since, without the ability to perform multistage modeling, estimating all commodity cross-price elasticities from a given data set is often impossible. Each of these properties permits specification of individual econometric models that require estimation of fewer parameters. Therefore, we require less information from the usually limited and imperfect data available.

This article exploits the analytic simplification opportunities permitted when production data exhibit reasonable consistency with homothetic separability and/or nonjointness properties. The objective is to estimate complete matrices of output supply and input demand elasticities for four major, geographically separated, agricultural States (California, Iowa, Texas, and Florida), each of which produces a large number of commercial agricultural products. Both own- and cross-price elasticities will be computed at the individual commodity level.

Model Specification

We assumed that the collection of producers in each State behaved like a price-taking, profit-

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[1]Sources are listed in the references section at the end of this article.

maximizing firm with a State-level aggregate production function, and modeled each State as though it was a perfectly competitive firm. We assumed regularity conditions on the production function to assure that a twice-continuously-differentiable dual profit function could be derived. Application of Hotelling's lemma to the profit function yielded a set of output supply and input demand functions for each State. Based on the results of functional form tests conducted by Ornelas, Shumway, and Ozuna (1991), who used U.S. agricultural data, we modeled the aggregate State-level restricted profit function by using the normalized quadratic functional form:

$$\pi = b_0 + \Sigma_{i=1}^{m} b_i p_i + \Sigma_{i=m+1}^{n} b_i z_i + 0.5\,(\Sigma_{i=1}^{m} \Sigma_{j=1}^{m} b_{ij} p_i p_j + \Sigma_{i=m+1}^{n} \Sigma_{j=m+1}^{n} b_{ij} z_i z_j) + \Sigma_{i=1}^{m} \Sigma_{j=m+1}^{n} b_{ij} p_i z_j, \qquad (1)$$

where π is profit (receipts less variable costs) divided by the price of netput (input or output) 0, $p_1,\ldots,p_m$ are the output and variable input prices divided by the price of netput 0, $z_{m+1},\ldots,z_n$ are fixed input quantities and other nonprice exogenous variables, and b_0, b_i, and b_{ij} are parameters.

To maintain consistency with the competitive theory and a twice-continuously-differentiable technology, linear homogeneity of the profit function in prices was applied through normalization (that is, dividing profit and prices by the price of netput 0), and symmetry (reciprocity) conditions among the first-derivative equations were imposed via linear parameter restrictions. Convexity was maintained by using the Cholesky factorization (Lau, 1978). Monotonicity was not maintained but was checked at each observation. The estimation system consisted of the first-derivative output supply and input demand equations:

$$\partial\pi/\partial p_i = x_i = b_i + \Sigma_{j=1}^{m} b_{ij} p_j + \Sigma_{j=m+1}^{n} b_{ij} z_j, \quad \text{for } i = 1,\ldots,m, \qquad (2)$$

where $x_1,\ldots,x_m$ are the netput quantities, positively measured for outputs and negatively measured for inputs.

By subtracting these price-weighted supply and demand equations from the normalized restricted profit function, we obtained the numeraire equation (the quantity supplied of netput 0):

$$x_0 = \pi - \Sigma_{i=1}^{m} p_i(\partial\pi/\partial p_i) = b_0 + \Sigma_{i=m+1}^{n} b_i z_i - 0.5(\Sigma_{i=1}^{m} \Sigma_{j=1}^{m} b_{ij} p_i p_j) + 0.5(\Sigma_{i=m+1}^{n} \Sigma_{j=m+1}^{n} b_{ij} z_i z_j), \qquad (3)$$

which is a quadratic function in normalized prices and fixed inputs.

When the underlying technology is homothetically separable in a partition of variables, data within the partition can be consistently aggregated and consistent multistage choices can be conducted. Assuming the same functional form as for the aggregated model, the normalized quadratic suboptimization (second-stage) model for the separable partition, s, was:

$$\pi_s + b_{0s} + \Sigma_{i=1}^{m} b_{is}\, p_{is} + \Sigma_{i=m+1}^{n} b_{is}\, z_{is} + 0.5(\Sigma_{i=1}^{m} \Sigma_{j=1}^{m} b_{ijs}\, p_{is} p_{js} + \Sigma_{i=m+1}^{n} \Sigma_{j=m+1}^{n} b_{ijs} z_{is} z_{js}) + \Sigma_{i=1}^{m} \Sigma_{j=m+1}^{n} b_{ijs} p_{is} z_{js} + c_s q_s + \Sigma_{i=1}^{m} c_{is} p_{is} q_s + \Sigma_{i=m+1}^{n} c_{is} z_{is} q_s + 0.5 d_s q_s^2, \qquad (4)$$

where π_s is normalized profit for the subset, $p_{1s},\ldots,p_{ms}$ are the normalized prices within the separable subset, $z_{m+1,s},\ldots,z_{ns}$ are the exogenous variables not included in the homothetic separability tests, q_s is the aggregate netput quantity index of the separable subset, and b_{0s}, b_{is}, b_{ijs}, c_s, c_{is}, and d_s are parameters.

Applying Hotelling's lemma to equation 4, we obtained the system of allocation equations:

$$\partial\pi_s/\partial p_{is} = x_{is} = b_{is} + \Sigma_{j=1}^{m} b_{ijs} p_{js} + \Sigma_{j=m+1}^{n} b_{ijs} z_{js} + c_{is} q_s, \quad \text{for } i = 1,\ldots,m, \qquad (5)$$

where $x_{1s},\ldots,x_{ms}$ are the allocation equations for the suboptimization model. By subtracting the price-weighted allocation equations from equation 4, we determined the quantity supplied of netput 0 (numeraire equation) of the subset:

$$x_{0s} = \pi_s - \Sigma_{i=1}^{m} p_{is}\partial\pi_s/\partial p_{is} = b_{0s} + \Sigma_{i=m+1}^{n} b_{is} z_{is} - 0.5(\Sigma_{i=1}^{m} \Sigma_{j=1}^{m} b_{ijs} p_{is} p_{js}) + 0.5(\Sigma_{i=m+1}^{n} \Sigma_{j=m+1}^{n} b_{ijs} z_{is} z_{js}) + c_s q_s + \Sigma_{i=m+1}^{n} c_{is} z_{is} q_s + 0.5 d_s q_s^2, \qquad (6)$$

which is a quadratic function in the normalized prices, aggregate index, and other exogenous variables.

Third-stage suboptimization models were formulated whenever the suboptimization model, equation 4, included an aggregate price index among the

normalized prices within the separable subset. These models were constructed following the pattern described in equation 4, and their allocation equations were obtained from their derivatives as in equations 5 and 6.

Data and Variable Specification

Annual State-level data compiled by Evenson and others (1986) for the period 1951-82, and updated to 1986 by McIntosh (1989a), supported this article. Output prices and quantities were included for as many as 14 field crops, four vegetables, four fruit crops, and seven livestock commodities, plus residual crop and livestock categories that consisted of other commercial food and fiber production for the given State. Variable input prices and quantities were included for fertilizer, pesticides, hired labor, machinery operating inputs, miscellaneous variable inputs, and capital services. Quantity data were included for the fixed input categories, land and family labor. The aggregate models included such exogenous variables as expected output prices, current variable input prices, and quantities of the fixed inputs (land and family labor), time, temperature, precipitation, and effective diversion payments.

Because of the large number of individual outputs (as many as 25 in some States) and input categories (8) and the limited number of data observations available (36), it was at first necessary to aggregate the data. Based on common nonrejected nonparametric separability tests using 1956-82 data for each of these States, this aggregation included four output categories and three variable input categories (Lim and Shumway, 1992). The output aggregates were crops, meat animals, milk-poultry, and other livestock. The meat animals category included cows and calves, hogs and pigs, and sheep and lambs. The milk-poultry category included milk, eggs, broilers, and turkeys. The other livestock category included all remaining commercial food animal commodities not included in the meat animal or milk-poultry aggregates. The variable input categories were labor-capital, materials, and pesticides. The labor-capital category included hired labor, machinery operating inputs, and capital services. The materials category included fertilizer and miscellaneous variable inputs. We aggregated all price categories using the Tornqvist index.

The variable-input category, pesticides, and the two fixed-input categories, family labor and land, were not aggregated further in the aggregate models. Pesticide price and quantity data were provided by McGath (1989) at the Economic Research Service. A weighted average of effective diversion payments for farm program crops was constructed using profit shares in the respective States as weights.

Villezca and Shumway's (1992) findings furnished final aggregate models built to be consistent with nonrejected parametric hypothesis tests of nonjointness and/or homothetic separability. They tested these structural properties in all four States using three different functional forms. They concluded that shortrun output category supply equations in California can be specified as functions only of their own prices, prices of variable inputs, and quantities of the nonprice exogenous variables. The same conclusion applies to crops and other livestock in Texas and Iowa, and to crops and meat animals in Florida. No justification was found for a higher level of data aggregation than already maintained in the initial model design.

Guided by Lim's (1989) findings, 1-year lagged output prices were used as the expected market prices. In using a procedure adapted from Romain (1983), we expected prices of farm program commodities (corn, milk, cotton, sorghum, barley, wheat, oats, soybeans, rice, sugarbeets, peanuts, and tobacco) to be specified as weighted averages of the anticipated market price and effective support price. The weights were dependent on the relative magnitudes of the expected market prices and support prices. McIntosh's (1990) findings favored the use of this specification in three of the States. The specification of effective diversion payments and effective support prices followed Houck and Ryan (1972). The simple average of the maximum and minimum values of these variables compiled by McIntosh (1989b) were used in the specification.

Weather variables were cropland-weighted State averages of monthly temperature and totals of monthly precipitation for critical growing months or for the calendar year (Teigen and Singer, 1988). Exploratory analysis was conducted to determine which weather variable specification provided the greatest explanatory power in each State. The weather variables chosen were annual average temperature and annual total precipitation in California, April-May average temperature and July-August total precipitation in Iowa, March-April average temperature and June-July total precipitation in Texas, and March-April average temperature and June-August total precipitation in Florida.

Second-stage suboptimization, employing corresponding price and quantity disaggregated data, was conducted for crops, meat animals, milk-poultry, materials, and labor-capital categories in each State. Third-stage suboptimization models covered crop categories that had to be aggregated in

the second stage due to the large number of individual crops for a given State. Nonprice exogenous variables included in all suboptimization models were the same as in the aggregate models, except for land and family labor. For the multistage model structure, as in the case of the aggregate models, we aggregated the data into output and variable input categories based on the separability test results obtained by Lim and Shumway (1992). Since neither the weak separability tests conducted by them nor the homothetic separability tests conducted by Villezca and Shumway (1992) on the aggregate models included the nonprice exogenous variables of temperature, precipitation, time, or effective diversion payments, these variables were included in all the multistage choice models for each State.

Estimation Procedure

For the first-stage (aggregate) models, systems of four output supply equations (crops, meat animals, milk-poultry, and other livestock) and two input demand equations (materials and pesticides) were estimated for each State as specified in equation 2. The capital-labor input price was used to normalize profit and all other output and variable input prices. Because of high collinearity in some State models, neither the profit function, equation 1, nor the numeraire, equation 3, was included in the aggregate systems of estimation equations. Nevertheless, because of shared parameters and homogeneity restrictions, all price elasticities for the numeraire equations were derived from the estimated systems.

Systems of output supplies and input demands estimated for the second-stage suboptimization (allocation) models, as specified in equations 5 and 6, are detailed for each State in table 1. Because of the large number of crops, we estimated third-stage suboptimization models for at least one crop category in each State. The numeraire, equation 6, was included in each estimated suboptimization model system estimated. Because of high collinearity in several models, parameters on the quadratic terms of the nonprice exogenous variables were not estimated in any of the suboptimization models. This exclusion reduced the flexibility of the functional form used for the suboptimization models by imposing cross-equation restrictions on comparative statics among the fixed inputs at the point of approximation.

Error terms associated with each model were assumed to be additive and independently and identically distributed with mean zero and a constant contemporaneous covariance matrix. The covariance matrix that transformed the observation matrix came from the iterative version of Zellner's seemingly unrelated regression (ITSUR). Using the procedure SYSNLIN ITSUR in the SAS package, the variance-covariance matrix was iterated until it stabilized for each model. The Cholesky factorization allowed imposition of the nonlinear inequality restrictions for maintaining convexity. With the convexity restrictions imposed, and using the observation matrix transformed by the iterated covariance matrix, we employed a reduced-gradient nonlinear program (Talpaz and others, 1989) by using the algorithm code MINOS 5.1 (Murtagh and Saunders, 1983) to obtain least squares estimates that satisfied curvature properties for each system of output supply and input demand equations. Model estimates were subject to homogeneity, symmetry, and convexity in prices and nonrejected nonjointness hypotheses.

Results

Table 2 shows summary statistics for the aggregate and each suboptimization model for each State. A 0.05 level of significance was used throughout this study in drawing conclusions from hypothesis tests. Curvature properties were tested against the nonconvex alternative using the test from Talpaz and others, and were not significantly violated in any State for any aggregate or suboptimization model. For the aggregate models, two nonsignificant monotonicity violations occurred in California, six jointly significant violations in Iowa, no violations in Texas, and three nonsignificant violations in Florida. Among the 27 suboptimization models, monotonicity was significantly violated in only three (California feed and food grains, Texas oil crops, and Florida meat animals). Consequently, one set of model estimates in each State significantly violated the implications of the competitive theory for individual firms. However, all significant violations were limited to the first six observations of the data period. No significant violations occurred at the most recent observation (for which elasticities were derived).

Given the model specification, the number of significant parameter estimates varied from 26 percent in the Iowa crops suboptimization model to 72 percent in the Iowa labor-capital suboptimization model. Across models, the proportion of significant parameter estimates was 33 percent in California, 36 percent in Iowa, 40 percent in Texas, 33 percent in Florida, and 36 percent in all States combined.

Multistage model estimates at the most recent observation (1986) produced disaggregated price elasticities for each State. Equations 2, 5, and 6 determined the elasticities for individual commodities

Table 1—Output supply and input demand equations estimated for multistage suboptimization models in the four States

Model	California	Iowa	Texas	Florida
Second-stage allocation		*Crops*		
	Feed and food grains (A) Fruit and vegetables (A) Cotton Sugarbeets Hay Other crops (R) (N)	Feed and food grains (A) Soybeans Apples Hay Potatoes Other crops (R) (N)	Feed and food grains (A) Oil crops (A) Vegetables (A) Oranges Grapefruit Hay Other crops (R) (N)	Fruit and vegetables (A) Tobacco Soybeans Peanuts Corn Sugarcane Other crops (R) (N)
		Meat animals		
	Cattle Hogs Sheep (N)	Cattle Hogs Sheep (N)	Cattle Hogs Sheep (N)	Cattle Hogs (N)
		Milk-poultry		
	Milk Eggs Broilers Turkeys (N)	Milk Eggs Broilers Turkeys (N)	Milk Eggs Broilers Turkeys (N)	Milk Eggs Broilers (N)
		Materials		
	Fertilizer Miscellaneous variable Inputs (R) (N)	Fertilizer Miscellaneous variable Inputs (R) (N)	Fertilizer Miscellaneous variable Inputs (R) (N)	Fertilizer Miscellaneous variable Inputs (R) (N)
		Labor-capital		
	Hired labor Capital services Machinery operating (N)	Hired labor Capital services Machinery operating (N)	Hired labor Capital services Machinery operating (N)	Hired labor Capital services Machinery operating (N)
Third-stage allocation		*Feed and food grains*		*Fruit and vegetables*
	Wheat Rice Corn Barley Oats (N)	Wheat Corn Sorghum Oats (N)	Wheat Rice Corn Barley Sorghum Oats (N)	Oranges Grapefruit Tomatoes Lettuce Potatoes (N)
	Fruit and vegetables		*Vegetables*	
	Apples Grapes Grapefruit Oranges Onions Lettuce Tomatoes Potatoes (N)		Onions Lettuce Tomatoes Potatoes (N)	
			Oil crops	
			Cotton Soybeans Peanuts (N)	

A=aggregate category for which a higher level allocation model is estimated. R=residual aggregate category for which no further allocation can be estimated. N=the numeraire.

and inputs by applying the chain rule of calculus (tables 3-10). (Appendix table 1 summarizes all own-price elasticities.) Because of the large commercial agricultural output of these States, the supply elasticities reported here are the most detailed and comprehensive ever to appear in economic literature. Without the ability to do multistage modeling, it would have been impossible to estimate cross-price elasticities for such a large number of commodities from these data.[2] All cross-price

[2]Estimating all cross-price elasticities by a single model would be possible if the time series data were pooled across States. A sufficient condition for pooling the data is identical technologies across the pooled States. Although not tested here, this hypothesis was rejected by Polson and Shumway for all pairs of States in two contiguous production regions.

Table 2—Summary statistics of multistage models in the four States

State	Model	Convexity, F-statistic	Monotonicity: Number of violations[2]	Monotonicity: χ^2 statistic	Percent of significant parameters[1]
California	Aggregate	0.70	2	1.53	26.9
	Crops	.05	0		34.7
	Meat animals	1.28	0		38.9
	Milk-poultry	1.53	0		26.9
	Materials	[3]	0		36.4
	Labor-capital	[3]	0		61.1
	Feed and food grains	.19	1	5.86[1]	30.0
	Fruit and vegetables	.39	0		32.4
Iowa	Aggregate	1.20	6	49.77[1]	31.7
	Crops	.42	0		25.5
	Meat animals	.41	0		33.3
	Milk-poultry	.85	3	.63	34.6
	Materials	[3]	2	1.13	27.3
	Labor-capital	[3]	0		72.2
	Feed and food grains	.05	0		47.6
Texas	Aggregate	.29	0		39.7
	Crops	.57	0		30.5
	Meat animals	.38	0		38.9
	Milk-poultry	.11	0		26.9
	Materials	[3]	0		45.5
	Labor-capital	[3]	0		66.7
	Feed and food grains	.76	1	2.68	37.3
	Vegetables	.04	0		53.8
	Oil crops	.0002	5	29.49[1]	52.6
Florida	Aggregate	.49	3	7.24	30.2
	Crops	.20	3	.55	31.0
	Meat animals	.12	0		54.5
	Milk-poultry	.33	1	.003	44.4
	Materials	[3]	0		36.4
	Labor-capital	[3]	0		33.3
	Fruit and vegetables	.92	2	7.27[1]	28.6

[1]Significant at 0.05 level.
[2]Number of violations of monotonicity from a possible total of 36 times the number of equations estimated in the respective model.
[3]Unconstrained estimates satisfied convexity restrictions.

elasticities were estimated. To conserve space, however, some columns of elasticities are not reported in tables 3-10 because all elasticities in the column were zero to the third decimal place. Standard errors are not reported for these elasticities, being both complex and merely approximate. Nearly all of the elasticity estimates in each table were computed as a nonlinear function of parameters.

Output supply and input demand elasticities varied widely across States. Weighted averages of the expected market price and effective support price acted as the expected output prices of farm program commodities, so differences in response to government programs and market price information are reflected by the wide range of own- and cross-price elasticities across States.

Crop Supply Elasticities

Nearly all own-price output supply elasticities were inelastic in each State. Exceptions included wheat and apples in Iowa, barley and oats in Texas, and tobacco and soybeans in Florida. With very few exceptions, cross-price output supply elasticities were also inelastic. Similarities among own-price responses (differences of 0.2 or less) across all States comprised potatoes, tomatoes (not produced in Iowa), and the other-crops residual category. Similarities across pairs of States numbered wheat, rice, corn, grapefruit, oranges, onions, and cotton in California and Texas, oranges and lettuce in California and Florida, and soybeans and hay in Iowa and Texas. Some of these responses were virtually the same (differences of 0.05 or less) in some State pairs, such as potatoes in California and Iowa; grapefruit, corn, and tomatoes in California and Texas; potatoes and tomatoes in California and Florida; and the other-crops residual category in Texas and Florida.

The signs of the cross-price elasticities indicated a wide variety of shortrun competitive and comple-

Table 3—Crop supply elasticities, California, 1986

Item	Wheat	Rice	Corn	Barley	Oats	Cotton	Sugar-beets	Hay	Onions	Lettuce	Toma-toes	Pota-toes	Apples	Grapes	Oranges	Grape-fruit	Other crops	Fert-ilizer	Misc. inputs	Pest-icides	Hired labor	Capital serv.	Mach. oper.
	Elasticity with respect to the price of:[1]																						
Wheat	0.070	0.052	0.045	0.021	0.001	–0.051	0.170	–0.034	0.002	0.006	0.008	0.003	0.001	0.012	0.006	0.001	0.037	–0.006	–0.070	0.021	–0.173	–0.068	–0.052
Rice	.037	.072	–.049	.014	.030	–.028	.093	–.019	.001	.003	.004	.001		.007	.003		.020	–.003	–.038	.012	–.094	–.037	–.029
Corn	.015	–.086	.344	–.129	–.114	–.009	.028	–.006		.001	.001			.002	.001		.006	–.001	–.012	.004	–.029	–.011	–.009
Barley	.009	.013	–.254	.181	.075	–.006	.021	–.004		.001	.001			.002	.001		.005	–.001	–.009	.003	–.022	–.009	–.007
Oats	–.019	.821	–2.462	.830	.857	–.007	.025	–.005		.001	.001			.002	.001		.005	–.001	–.010	.003	–.025	–.010	–.008
Cotton	–.006	–.005	–.004	–.002		.674	–.202	–.127	–.006	–.023	–.030	–.010	–.003	–.047	–.024	–.003	.150	–.006	–.067	.020	–.165	–.065	–.050
Sugarbeets	.093	.071	.057	.027	.002	–.671	.396	.062	.005	.018	.023	.008	.003	.037	.019	.002	–.152						
Hay	–.040	–.031	–.024	–.012	–.001	–.916	.143	.758	.089	.345	.447	.152	.051	.698	.363	.038	–1.740	–.005	–.065	.019	–.159	–.063	–.048
Onions						–.027	.005	.037	.013	.015	.011	.003	.008	.031	.023	.019	–.080	–.001	–.012	.004	–.029	–.011	–.009
Lettuce						–.011	.002	.015	.001	.082		.025	–.018	.046	–.047	–.040	–.032		–.005	.001	–.011	–.005	–.003
Tomatoes						–.046	.009	.063	.006	.025	.068	.008	.011	.058	.015	.021	–.137	–.002	–.020	.006	–.050	–.020	–.015
Potatoes						–.009	.002	.013	–.003	.076	–.019	.130	–.008	.027	–.093	–.069	–.027		–.004	.001	–.010	–.004	–.003
Apples						–.013	.003	.018	.015	–.186	.088	–.022	.096	–.126		.195	–.039		–.006	.002	–.014	–.006	–.004
Grapes						–.047	.010	.065	.008	.052	.037	.018	–.004	.083	.037	–.014	–.140	–.002	–.021	.006	–.051	–.020	–.015
Oranges	–.001					–.067	.014	.093	.013	.002	.043	–.005	.006	.100	.149	.002	–.201	–.002	–.030	.009	–.073	–.029	–.022
Grapefruit	–.001	–.001				–.075	.015	.104	.046	–.258	.227	–.140	.157	–.120	.026	.409	–.224	–.003	–.033	.010	–.081	–.032	–.025
Other crops						.006	–.002	–.026	–.002	–.008	–.010	–.003	–.001	–.015	–.008	–.001	.217	–.002	–.030	.009	–.073	–.029	–.022

[1]Blanks = elasticity was zero to third decimal place.

Table 4—Livestock supply and input demand elasticities, California, 1986

Item	Wheat	Rice	Corn	Barley	Cotton	Sugar-beets	Hay	Onions	Lettuce	Toma-toes	Pota-toes	Apples	Grapes	Oranges	Grape-fruit	Other crops	Cattle	Hogs	Sheep	Milk	Eggs	Broil-ers	Tur-keys	Other live-stock	Fert-ilizer	Misc. inputs	Pest-icides	Hired labor	Capital serv.	Mach. oper
	Elasticity with respect to the price of:[1]																													
Cattle																	0.133	–0.002	0.005						–0.027	–0.322	0.052	0.095	0.038	0.029
Hogs																	–.179	.138	.041							–.001				
Sheep																	–.031	.024	.007							–.001				
Milk																				0.042	0.007	0.006	0.004		–.007	–.086	.020	.008	.003	.002
Eggs																					.094	–.133	.038							
Broilers																				.060	–.139	.246	–.083		–.010	–.123	.029	.012	.005	.004
Turkeys																				.082	.071	–.104	.068		–.014	–.170	.040	.016	.006	.005
Other livestock																								0.022	.012	.144	.019	–.116	–.046	–.035
Fertilizer	0.001	0.001	0.001		0.004	0.001		0.001	0.002	0.003	0.001		0.005	0.003		0.030	.053	.002	.003	.037	.006	.005	.004	–.002	–.032	–.224	.042	.031	.012	.009
Misc. inputs	.001	.001	.001		.005	.001		.001	.003	.004	.001		.006	.003		.038	.067	.002	.003	.047	.008	.007	.005	–.002	–.024	–.299	.053	.040	.016	.012
Pesticides	–.003	–.003	–.002	–.001	–.011	–.003	–0.001	–.002	–.007	–.010	–.003	–0.001	–.015	–.008	–0.001	–.091	–.087	–.003	–.004	–.088	–.015	–.012	–.009	–.003	–.035	.422	–.091	.010	.004	.003
Hired labor	.006	.004	.003	.002	.019	.005	.002	.003	.013	.016	.006	.002	.025	.013	.001	.153	–.033	–.001	–.002	–.007	–.001	–.001	–.001	.003	.005	.065	.002	–.705	.180	.223
Capital services	.005	.004	.003	.002	.017	.004	.002	.003	.012	.015	.005	.002	.024	.012	.001	.142	–.030	–.001	–.002	–.007	–.001	–.001	–.001	.003	.005	.060	.002	.507	–1.068	.281
Machinery operating	.008	.006	.005	.002	.028	.007	.003	.005	.019	.025	.008	.003	.038	.020	.002	.230	–.049	–.002	–.003	–.011	–.002	–.002	–.001	.005	.008	.098	.003	.732	.341	–1.528

[1]Blanks = elasticity was zero to third decimal place.

Table 5—Crop supply elasticities, Iowa, 1986

Item	Elasticity with respect to the price of:[1]												
	Wheat	Corn	Oats	Soy-beans	Hay	Pota-toes	Apples	Other crops	Fert-ilizer	Misc. inputs	Pest-icides	Capital serv.	Mach. oper.
Wheat	2.079	–1.593	–0.471	0.007	–0.001				–0.003	–0.021	–0.002	0.003	0.002
Corn	–.002	.010	.001	.004					–.002	–.012	–.001	.002	.001
Oats	–.049	.045	.013	.004					–.002	–.012	–.001	.002	.001
Soybeans		.003		.005	–0.003		–0.001	–0.002		–.002			
Hay		–.040	–.001	–.119	.095	–0.014	.008	.074		–.003			
Potatoes		.129	.002	.427	–.396	.170	.451	–.783		–.001			
Apples	–0.001	–.567	–.009	–1.602	.345	.699	3.542	–2.405		–.001			
Other crops		–.014		–.054	.037	–.013	–.027	.072					

[1]Blanks = elasticity was zero to third decimal place.

Table 6—Livestock supply and input demand elasticities, Iowa, 1986

Item	Elasticity with respect to the price of:[1]																	
	Corn	Oats	Soy-beans	Other crops	Cattle	Hogs	Sheep	Milk	Eggs	Broil-ers	Tur-keys	Other live-stock	Ferti-lizer	Misc. inputs	Pesti-cides	Hired labor	Capital serv.	Mach. oper.
Cattle					0.142	0.195	0.007	–0.051	–0.007	–0.001	–0.006		–0.034	–0.267	0.032	–0.001	–0.005	–0.003
Hogs					.022	.097	–.002	–.017	–.002		–.002		–.012	–.091	.011		–.002	–.001
Sheep					.282	–.285	.048	–.007	–.001		–.001		–.004	–.035	.004		–.001	
Milk					–.058	–.116	–.001	.119	.016	.006	.005		–.008	–.063	–.042	.013	.084	.044
Eggs					–.155	–.309	–.003	.308	.165	–.002	–.078		–.022	–.169	–.112	.035	.224	.117
Broilers								.257	–.045	.261	–.473							
Turkeys					–.048	–.097	–.001	.014	–.122	–.076	.307		–.007	–.053	–.035	.011	.070	.037
Other livestock												2.433	.247	1.931	–1.007	–.337	–2.143	–1.124
Fertilizer	0.035	0.001	0.015	0.001	.087	.174	.001	.018	.003		.002	–.008	–.570	.130	.006	.010	.063	.033
Misc. inputs	.019		.008		.047	.094	.001	.010	.001		.001	–.005	.037	–.274	.003	.005	.034	.018
Pesticides	.018		.007		–.056	–.112	–.001	.066	.009	.001	.008	.024	.004	.033	–.040	.003	.022	.012
Hired labor	–.005		–.002		.002	.004		–.026	–.004		–.003	.010	.009	.068	.004	–.921	1.833	–.967
Capital services	–.008		–.003		.003	.005		–.037	–.005	–.001	–.004	.014	.012	.097	.006	.301	–1.047	.666
Machinery operating	–.005		–.002		.002	.004		–.025	–.004		–.003	.010	.008	.066	.004	–.314	1.330	–1.069

[1]Blanks = elasticity was zero to third decimal place.

Table 7—Crop supply elasticities, Texas, 1986

Item	Elasticity with respect to the price of:[1]																				
	Wheat	Rice	Corn	Barley	Sorghum	Oats	Soybeans	Peanuts	Cotton	Hay	Onions	Lettuce	Tomatoes	Potatoes	Oranges	Grapefruit	Other crops	Misc. inputs	Pesticides	Hired labor	Capital serv.	Mach. oper.
Wheat	0.190	0.052	0.158	0.002	0.220	0.009	-0.016	-0.058	-0.376	0.023	-0.001			-0.001	-0.010	-0.030	-0.161		0.003	-0.001	-0.002	0.002
Rice	.094	.187	-.211	.002	.122	.099	-.008	-.027	-.175	.011	-.001				-.005	-.014	-.075		.001		-.001	-.001
Corn	.160	-.049	.370	-.021	.177	-.094	-.014	-.050	-.323	.020	-.001				-.009	-.026	-.139		.003	-.001	-.002	-.001
Barley	.178	.092	-2.065	3.949	-1.939	.354	-.015	-.052	-.338	.021	-.001			-.001	-.009	-.027	-.145		.003	.001	-.002	-.002
Sorghum		.005	-.009	-.016	.011	.009																
Oats	.730	.953	-1.893	.092	1.106	1.341	-.061	-.214	-1.385	.086	-.004			-.002	-.038	-.110	-.595	0.001	.011	-.004	-.007	-.006
Soybeans	-.212	-.056	-.179	-.002	-.245	-.009	.059	.265	.521	-.036	-.038	-0.003	-0.004	-.018	.026	.038	-.103	.001	.010	-.003	-.007	-.005
Peanuts	-.033	-.009	-.028		-.039	-.001	.039	.206	-.111	-.006	-.006		-.001	-.003	.004	.006	-.016		.002	-.001	-.001	-.001
Cotton	-.162	-.043	-.137	-.002	-.188	-.007	.016	-.042	.590	-.028	-.029	-.002	-.003	-.014	.020	.029	-.079	.001	.007	-.003	-.005	-.004
Hay	.098	.026	.083	.001	.113	.004	-.012	-.042	-.270	.015	.014	.001	.001	.007	-.008	-.016	-.014	.001	.005	-.002	-.004	-.003
Onions	-.003	-.001	-.003		-.004		-.008	-.030	-.191	.010	.201	-.048	-.004	-.053		.001	.135					
Lettuce	-.010	-.003	-.008		-.011		-.024	-.083	-.537	.027	-.531	.340	.141	.321	-.001	.001	.378					
Tomatoes											-.113	.117	.094	-.098								
Potatoes	-.005	-.001	-.004		-.006		-.012	-.043	-.277	.014	-.152	.061	-.016	.246	-.001	.001	.195					
Oranges	-.901	-.240	-.763	-.009	-1.042	-.039	.178	.628	4.068	-.166	-.014	-.001	-.001	-.006	.260	.201	-2.137	.003	.033	-.011	-.022	-.018
Grapefruit	-2.527	-.674	-2.140	-.024	-2.924	-.109	.246	.866	5.612	-.324	.016	.001	.001	.007	.196	.415	1.369	.002	.017	-.006	-.011	-.009
Other crops	-.038	-.010	-.032		-.044	-.002	-.002	-.007	-.043	-.001	.011	.001	.001	.005	-.006	.004	.164		.001		-.001	-.001

[1] Blanks = elasticity was zero to third decimal place.

Table 8—Livestock supply and input demand elasticities, Texas, 1986

Item	Elasticity with respect to the price of:[1]																					
	Wheat	Rice	Corn	Sorghum	Peanuts	Cotton	Hay	Onions	Other crops	Cattle	Hogs	Sheep	Milk	Eggs	Broilers	Turkeys	Fertilizer	Misc. inputs	Pesticides	Hired labor	Capital serv.	Mach. oper
Cattle																		0.001			-0.001	
Hogs										-0.010	0.013	-0.003	-0.001		-0.001		0.001	.005	0.001	-0.001	-0.002	-0.002
Sheep										.002	-.004	.001										
Milk													.051	-0.015	-.029	0.001	-.002	-.021	-.006	0.004	0.009	0.007
Eggs										-.002			-.013	.031	.055		-.018	-.173	-.047	0.037	0.072	0.060
Broilers										-.002			-.023	.028	.087	-.038	-.014	-.129	-.035	0.027	0.054	0.044
Turkeys										-.010			.164	.052	-.189	.285	-.079	-.749	-.202	0.159	0.313	0.258
Other livestock																		-.001	-.001		0.001	0.001
Fertilizer										-.004			.058	.022	.037	.003	-.383	.292	-.024	0.018	0.036	0.030
Misc. inputs										-.005			.079	.030	.050	.003	.025	-.149	-.032	0.025	0.049	0.040
Pesticides	-0.004	-0.001	-0.004	-0.005	-0.001	-0.009	-0.001	-0.001	-0.013	-.005			.078	.030	.049	.003	-.046	-.437	-.210	0.126	0.248	0.204
Hired labor	.001			.001		.001			.002	0.02			-.024	-.009	-.015	-.001	.014	.133	.049	-1.085	0.094	0.837
Capital services						.001			.001	.001			-.018	-.007	-.011	-.001	.011	.099	.037	0.063	-0.954	0.775
Machinery operating	.001		.001	.001		.002			.002	.002			-.032	-.012	-.020	-.001	.019	.178	.066	0.558	0.912	-1.677

[1] Blanks = elasticity was zero to third decimal place.

Table 9—Crop supply elasticities, Florida, 1986

Item	Corn	Soy-beans	Peanuts	Sugar-cane	To-bacco	Lettuce	Toma-toes	Pota-toes	Oranges	Grape-fruit	Other crops	Fert-ilizer	Misc. inputs	Pest-icides	Hired labor	Capital serv.	Mach. oper.
	Elasticity with respect to the price of:[1]																
Corn	0.560	−0.062	0.512	−0.157	0.512	−0.006	−0.068	−0.012	−0.152	−0.035	−1.088		−0.001		−0.001	−0.001	
Soybeans	−.088	1.408	.364	−.518	−.092	−.015	−.168	−.029	−.375	−.085	−.391	−0.001	−.004		−.003	−.002	−0.001
Peanuts	.206	.103	.651	−.008	−.090	.005	.052	.009	.117	.027	−1.072						
Sugarcane	−.009	−.021		.113	.007	.001	.015	.003	.034	.008	−.088	−.006	−.024	−0.002	−.016	−.010	−.005
Tobacco	.514	−.065	−.223	.106	1.079	−.018	−.194	−.033	−.434	−.099	−.630		−.001		−.001		
Lettuce	−.008	−.016	.021	.040	−.026	.010	.036	−.014	.090	−.044	.031	−.011	−.046	−.004	−.030	−.019	−.010
Tomatoes	−.007	−.012	.016	.031	−.020	.003	.023	−.002	.050	−.013	.024	−.008	−.036	−.003	−.023	−.015	−.008
Potatoes	−.004	−.007	.009	.017	−.011	−.008	−.018	.117	−.116	.057	.013	−.004	−.019	−.002	−.013	−.008	−.004
Oranges						.002	.007	−.010	.019	−.018							
Grapefruit	−.006	−.011	.014	.028	−.018	−.007	−.026	.019	−.049	.117	.022	−.007	−.032	−.003	−.021	−.013	−.007
Other crops	−.013	−.003	−.032	−.012	−.007		.005	.001	.010	.002	.162	−.010	−.044	−.004	−.029	−.018	−.009

[1] Blanks = elasticity was zero to third decimal place.

Table 10—Livestock supply and input demand elasticities, Florida, 1986

Item	Corn	Soy-beans	Peanuts	Sugar-cane	To-bacco	Lettuce	Toma-toes	Pota-toes	Oranges	Grape-fruit	Other crops	Cattle	Hogs	Milk	Eggs	Broil-ers	Other live-stock	Fert-ilizer	Misc. inputs	Pest-icides	Hired labor	Capital serv.	Mach. oper.
	Elasticity with respect to the price of:[1]																						
Cattle												0.060	0.004					−0.005	−0.023	−0.059	0.012	0.007	0.004
Hogs												.073	.006					−.006	−.028	−.072	.014	.009	.005
Milk														0.063	0.058	−0.120	0.005	.002	.007	−.003	−.006	−.004	−.002
Eggs														.168	.153	−.317	.012	.004	.018	−.009	−.015	−.009	−.005
Broilers														−.292	−.267	.559							
Other livestock														.015	.006	.007	.110	−.005	−.021	−.104	−.005	−.003	−.002
Fertilizer	0.001	0.001	0.001	0.008	0.001		0.005	0.001	0.010	0.002	0.037	.003		−.001	−.001	−.001	.001	−.233	.116	−.016	.033	.021	.011
Misc. inputs	.002	.002	.004	.028	.002	0.001	0.015	.003	.034	.008	.125	.011	.001	−.004	−.002	−.002	.004	−.026	−.370	−.056	.112	.071	.037
Pesticides	.001	.001	.001	.008	.001		.005	.001	.010	.002	.037	.089	.006	.007	.003	.003	.064	−.041	−.176	−.165	.073	.046	.024
Hired labor	.002	.001	.003	.020	.001	.001	.011	.002	.025	.006	.090	−.006		.004	.002	.002	.001	.029	.123	.025	−.962	.312	.308
Capital services	.001	.001	.002	.012	.001	.001	.007	.001	.015	.003	.056	−.004		.002	.001	.001	.001	.018	.076	.016	.552	−.684	−.078
Machinery operating	.001		.001	.007			.004	.001	.008	.002	.031	−.002		.001	.001	.001		.010	.042	.009	1.130	−.127	−1.119

[1] Blanks = elasticity was zero to third decimal place.

mentary production relationships.[3] A few similarities, however, were found across some States. In California, Texas, and Florida, relationships were competitive between oranges and potatoes and between potatoes and tomatoes. Complementarity occurred between lettuce and tomatoes. In California and Texas, where the most similarities were found, results revealed complementary relationships among wheat, rice, barley, and oats, and competitive relationships between rice and corn and between corn and barley. All feed and food grains were gross substitutes to cotton. Other relationships showed complementarity between oranges and grapefruit; grapefruit, onions, and tomatoes; lettuce and tomatoes; potatoes and lettuce; and competitiveness between potatoes and tomatoes and potatoes and onions. All vegetables were gross complements to hay and gross substitutes to cotton and the other-crops residual category. Hay and cotton were also gross substitutes. Fewer consistent cross-price production relationships played out between California and Florida and between Texas and Florida. Cross-price relationships in Iowa were least similar to those in other States.

Livestock Supply Elasticities

With only one exception (in Iowa), all own-price livestock elasticities were inelastic, ranging from 0.007 to 0.25 in California, 0.05 to 2.43 in Iowa, 0.001 to 0.29 in Texas, and 0.01 to 0.56 in Florida. All cross-price livestock output elasticities were inelastic in each State. Although not as varied in magnitude as the crop elasticities, the elasticities for livestock also reflected considerable variation across States. Similar own-price elasticities (that is, differences of 0.2 or less) were observed for milk and eggs and spanned all States; for hogs, sheep, and broilers in California, Iowa, and Texas; for cattle in California, Iowa, and Florida; for the other-livestock residual category in California and Florida; and for turkeys in Iowa and Texas. Virtually the same elasticities (differences of 0.05 or less) covered California, Texas, and Florida for milk, California and Iowa for cattle, hogs, and broilers, California and Texas for sheep, and Iowa and Florida for eggs.

Cross-price elasticities showed consistent signs across some States. Milk and turkeys qualified as shortrun gross complements and broilers and turkeys as shortrun gross substitutes in California, Iowa, and Texas. Gross substitutability occurred between eggs and broilers in California, Iowa, and Florida. Gross complementarity was observed between milk and broilers in California and Iowa; eggs and turkeys in California and Texas; cattle and hogs, and milk and eggs in Iowa and Florida. Gross substitutability marked hogs and sheep in Iowa and Texas, and milk and broilers in Texas and Florida. Since the estimation of the aggregate models for each State was performed maintaining nonjointness for at least the crops category, no livestock-crop nor crop-livestock cross-price elasticities were derived.

Input Demand Elasticities

Own-price input demand elasticities were also generally inelastic in each State. A common exception was machinery operating inputs, which ranged from –1.07 in Iowa to –1.68 in Texas. Own-price elastic responses also influenced capital services in California and Iowa and hired labor in Texas. Across States, similar elasticities spanned miscellaneous variable inputs and pesticides in all States; capital services in California, Iowa, and Texas; hired labor in Iowa, Texas, and Florida; fertilizer in Iowa and Texas and in Texas and Florida; and machinery operating inputs in California and Texas and in Iowa and Florida. Nearly identical elasticities turned up in some States: miscellaneous variable inputs, pesticides, and capital services in California and Iowa, pesticides in Texas and Florida, and hired labor and machinery operating inputs in Iowa and Florida.

Except for two elasticities in Iowa and one in Florida, all cross-price input demand relationships were inelastic. They ranged from 0.002 to 0.97 in absolute value. The signs of these elasticities revealed that all variable inputs were shortrun gross substitutes, except for fertilizer-miscellaneous variable inputs in California, hired labor-machinery operating inputs in Iowa, fertilizer-pesticides and miscellaneous variable inputs-pesticides in Texas, and fertilizer-pesticides, miscellaneous variable inputs-pesticides, and capital services-machinery operating inputs in Florida.

Output-input relationships showed that increases in the prices of inputs generally caused quantities of crops to decrease in all States, except for pesticides in California and Texas, capital services

[3]When all inputs and outputs are variable, economic incentive for a joint technology (in which one firm produces multiple outputs) exists only if outputs are longrun gross complements. Inputs must also be gross complements if multiple inputs are used economically by the same firm in the long run. There are two reasons why gross complementarity of either outputs or inputs is not a theoretical implication in the current context. First, our analysis is short run. Family labor and land are treated as fixed inputs. The impact of allocatable fixed inputs (such as labor and land) on shortrun cross-price output relationships is opposite to that of technical interdependence (which gives rise to joint production in the long run). Second, our analyses are for State aggregates rather than for individual firms. Externalities can give rise to either competitive or complementary relationships at the community (or larger geographic) level when they do not exist in the firm.

and machinery operating inputs in Iowa, and miscellaneous variable inputs in Texas. Because of symmetry restrictions on price parameters within a model, input demands generally increased as crop prices increased. Output-input responses for livestock showed a wide variation across States regarding the direction of the relationships between the quantities of livestock categories and the prices of several inputs and vice versa.

Conclusions

Disaggregated parameter estimates for multiple-output production relationships in California, Iowa, Texas, and Florida came from dual models that were consistent over most of the data period with competitive theory, nonrejected analytic simplifying assumptions (nonjointness), and multistage choice (homothetic separability). Linear homogeneity, symmetry, and convexity restrictions were maintained in the estimation. Monotonicity was checked at every observation and was significantly violated by only four of the 31 models estimated and only at early observations in the data period. Convexity was not rejected by any model.

The multistage parameter estimates were used to derive full matrices of disaggregated elasticities. Multistage modeling allowed these elasticities to be computed at the most detailed and comprehensive level ever to appear in economic literature.

A wide diversity among output supply and input demand elasticities was observed across States. Nearly all output supply elasticities for crops were inelastic and showed a wider variation across States than did livestock supplies or input demands. With only one exception, all livestock supply elasticities were also inelastic. A common pattern regarding the magnitude of the own-price supply elasticities (differences of 0.2 or less) across all States occurred only for potatoes, tomatoes, the other-crops residual category, milk, and eggs. Other important similarities were observed across pairs of States.

Input demand elasticities were generally inelastic. A common exception was machinery operating inputs, which showed an elastic response in all States. Own-price elasticities for miscellaneous variable inputs and pesticides appeared similar in all States. Important similarities in other elasticities were found in two or three States. Output-input relationships across States showed that, in general, crop supplies decreased as input prices increased, and input demands increased as crop prices increased.

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Appendix table 1—Output supply and input demand own-price elasticities, 1986

Output or input	California	Iowa	Texas	Florida
Wheat	0.070	2.079	0.190	NA
Rice	.072	NA	.187	NA
Corn	.344	.010	.370	0.560
Barley	.181	NA	3.949	NA
Sorghum	NA	NA	.011	NA
Oats	.857	.013	1.341	NA
Soybeans	NA	.005	.059	1.408
Peanuts	NA	NA	.206	.651
Cotton	.674	NA	.590	NA
Sugarbeets	.396	NA	NA	NA
Sugarcane	NA	NA	NA	.113
Hay	.758	.095	.015	NA
Tobacco	NA	NA	NA	1.079
Onions	.013	NA	.201	NA
Lettuce	.082	NA	.340	.010
Tomatoes	.068	NA	.094	.023
Potatoes	.130	.170	.246	.117
Apples	.096	3.542	NA	NA
Grapes	.083	NA	NA	NA
Oranges	.149	NA	.260	.019
Grapefruit	.409	NA	.415	.117
Other crops	.217	.072	.164	.162
Cattle	.133	.142	.000	.060
Hogs	.138	.097	.013	.006
Sheep	.007	.048	.001	NA
Milk	.042	.119	.051	.063
Eggs	.094	.165	.031	.153
Broilers	.246	.261	.087	.559
Turkeys	.068	.307	.287	NA
Other livestock	.022	2.433	.000	.110
Fertilizer	–.032	–.570	–.383	–.233
Miscellaneous	–.299	–.274	–.149	–.370
Pesticides	–.091	–.040	–.210	–.165
Hired labor	–.705	–.921	–1.085	–.962
Capital services	–1.068	–1.047	–.954	–.684
Machinery operating	–1.528	–1.069	–1.677	–1.119

NA = not applicable.

Assessing Rates of Return to Public and Private Agricultural Research

Jet Yee

Abstract. *Previous work on the rate of return to public agricultural research for the United States has neglected private agricultural research expenditures. This study, which factors in production variables like weather and the shifting health of the national economy over a 70-year period (1915-85), does include private research. When private research is omitted, the rate of return to public research rises by almost 20 percent. This finding supports the extension of Federal and State funding for agricultural research, especially if it can be coordinated with efforts in the private sector.*

Keywords. *Public agricultural research, private agricultural research, agricultural productivity, rate of return.*

Public investment in agricultural research has significantly boosted U.S. farm productivity. Is it worthwhile then for society to invest public funds in research and development (R&D)? A large number of studies have estimated the rate of return to public agricultural research (Ruttan, 1980, 1982; Echeverria, 1990).[1] Most of them found rather high rates of return. However, the only costs usually considered have been direct public research expenditures.

The omission of other production variables, however, may bias estimates of the rate of return to public agricultural research. Extension variables (Griliches, 1964; Huffman, 1978) or weather variables (White and Havlicek, 1982; Thirtle and Bottomley, 1988) have been featured in some studies. No previous work explicitly considers private agricultural research expenditures, which this article does in estimating the rates of return to public and private agricultural research. Huffman and Evenson (1989) take private research into account in their model. However, they use the number of patents in agricultural technology fields rather than private research expenditures. In addition, I introduce a new weather index, factor in the state of the general economy, and employ a much longer time series on research expenditures than most previous studies.

Model Specification and Data

R&D expenditures introduce a time lag that may affect productivity. First, a particular R&D project may take several years to complete. Second, when completed and if successful, it may take some time to decide whether to use it. Third, once a decision has been made to use it, it will affect productivity with a lag because the production process takes time. Fourth, after a number of years have passed, use of the technology will likely decline or even cease completely because a superior technology appears. These considerations suggest that the lag structure of R&D expenditures on productivity is quite complex. An inverted U-shaped or inverted V-shaped distribution may serve as a rough approximation.

My hypothesized production function is:

$$Q_t = A \prod_{i=1}^{l} X_{it}^{\sigma_i} \prod_{i=0}^{m} PUB_{t-i}^{\alpha_i} \prod_{i=0}^{n} PRI_{t-i}^{\beta_i} \; e^{\gamma_1 \mathrm{Ext}_t + \gamma_2 \mathrm{GNP}_{t-1} + \gamma_3 \mathrm{W}_t + u_t}, \qquad (1)$$

where Q is aggregate output, A is a constant, PUB_t (PRI_t) is public (private) research expenditures in period t, Ext is extension, GNP is gross national product (a proxy for the state of the general economy), W is a weather index, and u_t is an error term. The X_i's are conventional inputs, such as land, labor, capital, and materials. Define total factor productivity by:

$$P_t \equiv \frac{Q_t}{\prod_i X_{it}^{\sigma_i}} = A \prod_{i=0}^{m} PUB_{t-i}^{\alpha_i} \prod_{i=0}^{n} PRI_{t-i}^{\beta_i} \; e^{\gamma_1 \mathrm{Ext}_t + \gamma_2 \mathrm{GNP}_{t-1} + \gamma_3 \mathrm{W}_t + u_t}, \qquad (2)$$

where P is agricultural productivity. Estimate the σ_i's by the observed conventional input cost shares. Data on agricultural productivity and public and private agricultural research expenditures are from Langston (1988). Data for public agricultural research funding include only expenditures on production-related research by the U.S. Department of Agriculture and the State Agricultural Experiment Stations. Private research funding is taken from National Science Foundation data for research dollars spent on agricultural chemicals and farm machinery and is also derived from industry sales information.

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[1]Sources are listed in the references section at the end of this article.

Langston's compilation of private R&D expenditures data has several drawbacks. First, private R&D expenditures by food, seed, and veterinary pharmaceutical companies are not included. Data on such expenditures are unavailable for the early years. What data are available indicate that private R&D expenditures on agricultural chemicals and farm machinery far exceed those on seed and veterinary pharmaceuticals. The exclusion of R&D expenditures on new food products is not a major problem since this article considers the productivity of the farm sector, not the productivity of the agribusiness sector. Leaving out private R&D expenditures on seed and veterinary pharmaceuticals may bias the calculated rate of return to public R&D upward, with the actual direction of bias depending on how public and private R&D expenditures are correlated.

Second, private R&D expenditures before 1952 come from sales data and assume that a certain proportion of sales by farm input suppliers is spent on R&D. The proportion of sales spent on R&D is calculated for the years known and extrapolated to the unknown years. Langston gives several references to justify this assumption about research spending behavior.

The R&D expenditures data in Langston are in current dollars. I deflated R&D expenditures by a price deflator for agricultural R&D (Pardey, Craig, and Hallaway, 1989). The period of my estimation is 1931-85. However, data on public and private research expenditures covered 1915-85 to account for the lag structure of R&D expenditures on productivity (fig. 1).

Fluctuations in agricultural productivity growth are caused largely by changes in weather. I include a weather index in my model, first regressing crop production per acre on a constant and the first, second, third, and fourth powers of time for the period 1910-86. The data for crop production per acre are from the *Economic Report of the President*. I then used the estimated coefficients to obtain a fitted trend curve for crop production per acre. Any deviation of actual crop production per acre from trend is interpreted as a deviation in weather from "normal" conditions.

There is almost no change in trend crop production per acre from 1910 to the late 1920's (fig. 2). A long period of rapid growth in trend crop production per acre starts in the late 1920's. This growth slows after the early 1970's. The rise in trend crop produc-

Figure 1
Real public and private research expenditures

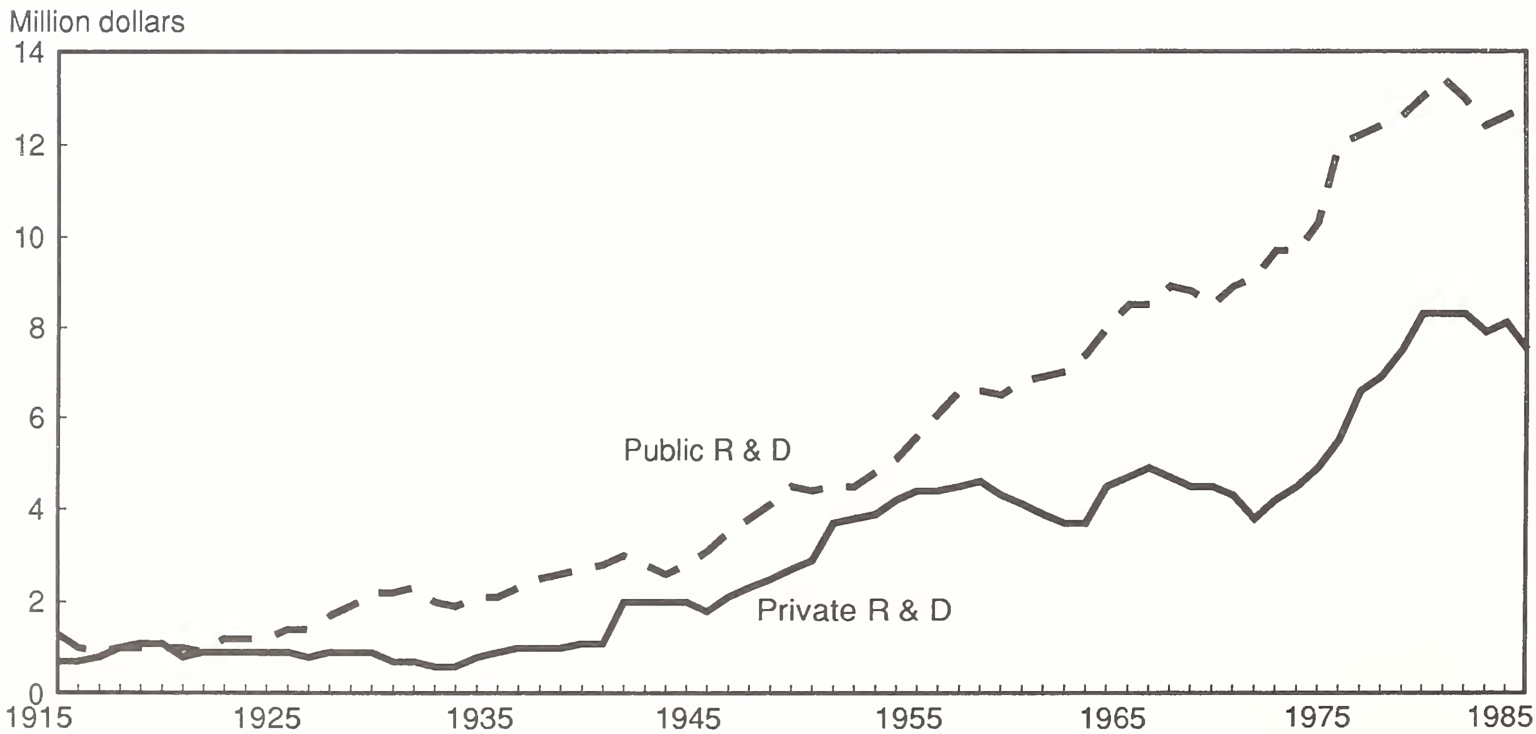
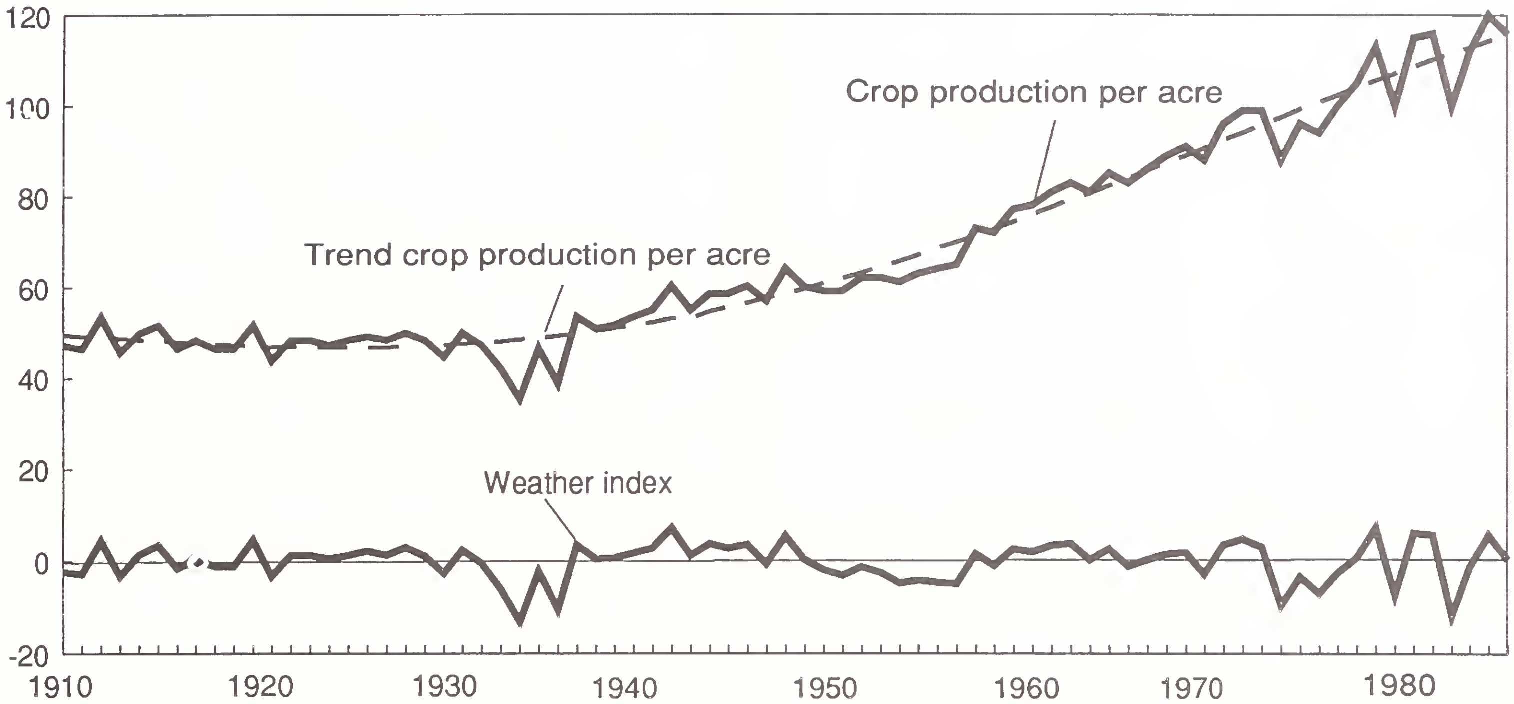


Figure 2
Crop production per acre and weather index, 1910-86



tion per acre can be attributed to increases in the quality and quantities of nonland inputs (for example, farm machinery and chemicals) and to the development of improved plant varieties like hybrid corn.

My weather index can show negative, zero, or positive values. The higher the value of the weather index, the better the weather for agricultural productivity. Extended periods of good weather, as indicated by the weather index, occurred in the 1940's, 1960's, and to a lesser extent, in the 1920's. The weather index is especially low for the mid-1930's, most of the 1950's, and the mid-1970's. Volatility in the weather index increased after the late 1970's. This increase in volatility suggests that the weather index includes nonweather factors, especially economic and policy. For example, the sharp drop in my weather index in 1983 may be traced to the influence of drought as well as the Payment-in-Kind (PIK) program.

The correlation coefficient of the weather index (W) and the ratio of annual total precipitation to annual mean temperature (P/T) were computed for several climatological stations from 1915-70 (using data from *Historical Statistics of the United States*). The correlation coefficients of W and P/T for climatological stations in California, Illinois, Montana, Nebraska, North Dakota, New York, Oklahoma, and South Dakota were 0.27, 0.24, 0.50, 0.34, 0.39, 0.27, 0.50, and 0.25. This suggests the weather index is a reasonable reflection of actual weather conditions. Note that the weather index was based on crop production per acre while the productivity measure was based on all outputs and all inputs.

I assumed that agricultural productivity also benefits from public extension. Extension is different from R&D in two respects. First, extension affects productivity mostly in the current period. Second, extension does not have the public-good nature of R&D. It is for these two reasons that I use extension stock (constructed using a depreciation rate of 50 percent) per farm as my extension variable. That is,

$$Ext_t = \frac{1}{n_t} \sum_{i=0}^{\infty} (1 - \delta)^i E_{t-i},$$

where Ext_t is real extension expenditures in period t, n_t is the number of farms in period t, and $\delta = 0.5$. Data on public extension expenditures are from Huffman and Evenson (1987). The data on the number of farms are from *Agricultural Statistics*.

Economic conditions have a hypothetical effect on incentives for innovation, with resulting economic and productivity growth in the agricultural sector. The notion that inventive activity is largely driven by demand has been most strongly advocated by Schmookler (1966), who showed that inventive activity (as measured by patents) was related to earlier movements in investment and output of the relevant industries. Real gross national product (GNP) acts as a proxy for the economic conditions facing the agricultural sector. (A reviewer suggested that a variable more directly related to the economic health of the agricultural sector may be preferable to real GNP. Real gross farm income performed slightly worse and real net farm income performed much worse than real GNP (in terms of t-statistics).) Since producers will likely respond to changing economic conditions with a lag, I used GNP lagged one period in estimation. The data for GNP are from the *Economic Report of the President.*

To estimate the parameters of equation 2, take the log of both sides to get a distributed lag model:

$$lnP_t = lnA + \sum_{i=0}^{m} \alpha_i \, lnPUB_{t-i} + \sum_{i=0}^{n} \beta_i lnPRI_{t-i}$$

$$+ \gamma_1 Ext_t + \gamma_2 GNP_{t-1} + \gamma_3 W_t + u_t. \qquad (3)$$

However, the large number of lagged variables are likely to be highly correlated, using up a large number of degrees of freedom. Thus, to estimate equation 3, I use the Almon (1965) distributed lag procedure, a method employed in previous studies, including Cline (1975), White and Havlicek (1982), and Thirtle and Bottomley (1988). I assumed that current public R&D (private R&D) has no effect on productivity for the first 3 (2) years, but, thereafter, effects last for the next 15 years. Private R&D expenditures are assumed to have a shorter time lag before having an effect on productivity to reflect the applied research (that is, short-term) orientation of much private research. The assumption that R&D expenditures have an effect on productivity over 15 years is consistent with previous studies, including Evenson (1968) and Cline (1975). I also assumed that the nonzero weights α_i's (β_i's) follow a second-degree polynomial $\alpha_i = a_0 + a_1 i + a_2 i^2$ ($\beta_i = b_o + b_1 i + b_2 i^2$) as per my earlier discussion suggesting an inverted U-shaped distribution. Imposing the endpoint restrictions $\alpha_3 = \alpha_{18} = 0$ and $\beta_2 = \beta_{17} = 0$ produces the equation to estimate:

$$lnP_t = lnA + a_2 lnS_{1t} + b_2 lnS_{2t}$$

$$+ \gamma_1 Ext_t + \gamma_2 GNP_{t-1} + \gamma_3 W_t + u_t, \qquad (4)$$

where $lnS_{1t} \equiv \sum_{i=4}^{17} (54 - 21i + i^2) \ln PUB_{t-i}$

and $lnS_{2t} \equiv \sum_{i=3}^{16} (34 - 19i + i^2) \ln PRI_{t-i}$.

The nonzero weights can be obtained as $\alpha_i = (54 - 21i + i^2) \cdot a_2$ and $\beta_i = (34 - 19i + i^2) \cdot b_2$. Derivations are given in the appendix.

Using the estimated parameters from the distributed lag model equation 3, one can estimate the rate of return to public agricultural research. The parameter estimates for the distributed lag coefficients in equation 3 are the output elasticities of the R&D variables for each year of the lag, for example:

$$\alpha_\tau = \frac{\partial lnP_t}{\partial lnPUB_{t-\tau}}. \qquad (5)$$

That is, α_τ gives the effect on current productivity of public R&D expenditures τ periods back.

The estimated α_τ's can be used to calculate the rate of return to public R&D as follows (from equation 5):

$$\alpha_\tau = \frac{\partial lnP_t}{\partial lnPUB_{t-\tau}} = \frac{\partial P_t}{\partial PUB_{t-\tau}} \cdot \frac{PUB_{t-\tau}}{P_t}. \qquad (6)$$

Rearrange equation 6 to get the marginal product of public R&D:

$$\frac{\partial P_t}{\partial PUB_{t-\tau}} = \alpha_\tau \frac{P_t}{PUB_{t-\tau}}. \qquad (7)$$

Multiplying both sides of equation 7 by $(\partial Y_t/\partial P_t)$, where Y is the value of output, yields:

$$\frac{\partial P_t}{\partial PUB_{t-\tau}} \cdot \frac{\partial Y_t}{\partial P_t} = \alpha_\tau \frac{P_t}{PUB_{t-\tau}} \cdot \frac{\partial Y_t}{\partial P_t}, \qquad (8)$$

or

$$VMP_{t,t-\tau} \equiv \frac{\partial Y_t}{\partial PUB_{t-\tau}} = \alpha_\tau \frac{P_t}{PUB_{t-\tau}} \cdot \frac{\partial Y_t}{\partial P_t}. \qquad (9)$$

Equation 9 gives the effect of public R&D expenditures in period $t-\tau$ on the value of output in period t. The rate of return (r) for an additional research expenditure of $\Delta PUB_{t-\tau}$ in period $t-\tau$ is the discount rate that results in the following equality:

$$\Delta PUB_{t-\tau} = \sum_{i=0}^{m} \frac{\Delta Y_{t-\tau+i}}{(1+r)^i}, \qquad (10)$$

or

$$\sum_{i=0}^{m} \frac{VMP_{t-\tau+i,t-\tau}}{(1+r)^i} - 1 = 0. \qquad (11)$$

Empirical Results

I estimated equation 4 by ordinary least squares (OLS) for 1931-85. Since the Durbin-Watson statistic from the OLS estimation was so low (1.26), I used the iterative Prais and Winsten algorithm implemented in LIMDEP to correct for autocorrelation. Table 1 shows the estimated parameters. The coefficients of extension, GNP, and weather are expected to be positive and the coefficients of $\ln S_1$ and $\ln S_2$ (see appendix) to be negative. All the estimated parameters have the expected signs. Public R&D, extension, and weather are significant at the 5-percent level. Private R&D is significant at the 10-percent level, while GNP is significant at the 20-percent level. The derived estimates of the α_i's and β_i's are also presented in table 1.

Using equations 9, 11, and the parameter estimates of equation 4, one can obtain the rate of return to public R&D. Used for Y, value of output, are cash marketing receipts from *Agricultural Statistics* deflated by the GNP deflator from the *Economic Report of the President*. Mean values for $(P_t/PUB_{t-\tau})$ and $(\partial Y_t/\partial P_t)$ are used in equation 9. For the period of estimation (1931-85), the geometric mean of P is 73.02 and the geometric mean of PUB is \$466.7 million. The mean value of $(\partial Y/\partial P)$ of nearly \$1.1 billion follows as the slope coefficient of a regression of Y on a constant and P. Using those values yields a calculated rate of return to public agricultural research of 49 percent.[2]

For comparison, I also estimated a model that omits private research to determine the bias that results from its exclusion (see the parameters in table 1). All the estimated parameters have the expected signs. Public R&D, extension, and weather are significant at the 5-percent level. GNP is significant at the 20-percent level. My estimate of the rate of return to public R&D rises to 58 percent when I omit private R&D.

Many studies have estimated the rate of return to public agricultural research. Most of them found rather high rates of return, usually in the 30- to 60-percent range (Ruttan, 1980, 1982; Echeverria, 1990). My estimates of the rate of return to public agricultural research of 58 percent without private research and 49 percent with private research are consistent with estimates presented in the literature.

[2]My procedures are standard in the production function approach to measuring the returns to R&D. A second approach for measuring returns to R&D estimates the consumer and producer surplus associated with R&D. See Norton and Davis (1981) for a review of studies that employ the consumer and producer surplus approach.

Table 1—Contribution of public and private R&D expenditures to U.S. agricultural productivity[1]

Explanatory variables	Dependent variables: lnP (with private R&D)	lnP (without private R&D)
Constant	3.86 (133.8)	3.84 (133.3)
$\ln S_1$	−.00031 (−2.16)	−.00047 (−3.68)
$\ln S_2$	−.00012 (−1.94)	
Ext	36.8 (2.47)	37.5 (2.25)
GNP	.00001 (1.62)	.00001 (1.39)
W	.0089 (8.72)	.0087 (8.66)

	Public R&D lag coefficients, α_i (with private R&D)	Private R&D lag coefficients, β_i	Public R&D lag coefficients, α_i (without private R&D)
t	0	0	0
t - 1	0	0	0
t - 2	0	0	0
t - 3	0	.0017	0
t - 4	.0043	.0031	.0066
t - 5	.0081	.0043	.0122
t - 6	.0112	.0053	.0169
t - 7	.0136	.0060	.0207
t - 8	.0155	.0065	.0235
t - 9	.0167	.0067	.0254
t - 10	.0174	.0067	.0263
t - 11	.0174	.0065	.0263
t - 12	.0167	.0060	.0254
t - 13	.0155	.0053	.0235
t - 14	.0136	.0043	.0207
t - 15	.0112	.0031	.0169
t - 16	.0081	.0017	.0122
t - 17	.0043	0	.0066
t - 18	0	0	0

	With private R&D	Without private R&D
ρ	0.384	0.467
DW	2.00	2.08
R^2	.984	.982
No. of obs.	54	54

[1]Estimates of equation 4 with and without private research.

Notes: T-statistics are shown in parentheses. P is agricultural productivity. Ext is extension stock per farm. GNP is real gross national product. W is a weather index. S_1 and S_2 are defined in the text. ρ is the estimated value of the first-order autoregressive coefficient of the disturbance terms. DW is the Durbin-Watson statistic (after correction for autocorrelation).

Most previous studies, however, explicitly considered only public research, obtaining their rate of return estimates by dividing the marginal product of public research by a factor of 3 to take into account the two omitted variables, private research and public extension. These studies assume that public research expenditures, private research expenditures, and extension expenditures are each about

equal. (See, for example, Griliches, 1964, p. 968; Bredahl and Peterson, 1976, p. 688; and White and Havlicek, 1982, p. 52.) Data suggest this may not be a good assumption. By contrast, my model explicitly takes into account private research expenditures and public extension expenditures as well as weather and the state of the general economy.

My estimate of the rate of return to private R&D based on the geometric mean of PRI (private research expenditures) of $302 million is 38 percent, almost 25 percent lower than the rate of return to public R&D. There are several possible explanations for the lower rate of return to private R&D. First, the main purpose of the private sector is to make profits and only indirectly to increase agricultural productivity. By contrast, one of the main goals of public agricultural research is to increase agricultural productivity. Second, a public extension system facilitates the adoption of public research results.

Third, private agricultural R&D grows from firms that think they will be able to appropriate all the returns to their R&D by increasing the prices of their outputs. These price increases should be reflected as quality changes in quality-adjusted price indexes and thus should already be taken into account in a constructed measure of total factor productivity for the agricultural sector. Private agricultural R&D may have little additional influence on agricultural productivity once the higher quality of the inputs has been taken into account. However, some private research spending must be accounted for if firms are not able to appropriate the full returns to their R&D investment, and the price indexes have not been quality-adjusted. Mansfield and others (1977) determined that the private rate of return to private research was about half the social rate of return.

While I found a higher rate of return to public R&D than private R&D in agriculture, studies of rates of return to R&D in manufacturing find just the opposite (Lichtenberg and Siegel, 1991). This difference may be because publicly funded R&D in manufacturing is mainly in areas in which it is difficult to measure productivity, such as in defense and space.

Conclusions

Taking private agricultural research, weather, extension, and the state of the general economy into account, I calculated a lower rate of return to private than public agricultural research. Future Federal and State funding for agricultural research should be continued in light of its high rate of return. However, the rate of return to public agricultural research has been overestimated since most studies have ignored private research expenditures. Decisions on the allocation of public research funds to various research areas should take into account the type and volume of research being conducted in the private sector.

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Appendix

Since $\alpha_i = 0$, for i = 0, 1, 2, 3, and $i \geqslant 18$,

$$\sum_i \alpha_i lnPUB_{t-i} = \sum_{i=4}^{17} (a_0 + a_1 i + a_2 i^2) lnPUB_{t-i},$$

on substituting for α_i. The endpoint restrictions, $\alpha_3 = \alpha_{18} = 0$, give two equations:

$\alpha_3 = a_0 + 3a_1 + 9a_2 = 0$, and

$\alpha_{18} = a_0 + 18a_1 + (18)^2 a_2 = 0$,

from which I can solve for a_0 and a_1 in terms of a_2:

$a_0 = 54a_2$ and $a_1 = -21a_2$.

Substituting for a_0 and a_1 gives:

$$\sum_{i=4}^{17} (54a_2 - 21a_2 i + a_2 i^2) \ln PUB_{t-i}$$

$$= a_2 \sum_{i=4}^{17} (54 - 21i + i^2) \ln PUB_{t-i}$$

$$= a_2 lnS_{1t},$$

and

$\alpha_i = a_0 + a_1 i + a_2 i^2$

$= 54a_2 - 21a_2 i + a_2 i^2$

$= (54 - 21i + i^2)a_2$.

The sign of a_2 is expected to be negative (for α_i to have a maximum). A similar procedure can be employed to obtain lnS_{2t} and β_i.

Johnson's "Disarray" Revisited

World Agriculture in Disarray. *Second edition. By D. Gale Johnson. New York: St. Martin's Press, 1991, 365 pages.*

Reviewed by Robert L. Paarlberg

Readers of the first edition (1973) of D. Gale Johnson's classic treatise against agricultural protectionism have a right to ask: Why a second edition? Were not the arguments clear enough the first time around? Are not some classics better left unaltered?

Fortunately, Johnson's second edition incorporates so much new material as to be of value in its own right. It may actually be of greatest value to those who are most familiar with the first edition.

The first book is deeply appreciated by serious scholars because it bravely challenged what in the 1970's was a powerful (nonscholarly) consensus that the world was soon to run out of food. Johnson's book argued the opposite. Industrial countries, he said, were embracing policies destined to generate excessive production by keeping too many resources in agriculture. Johnson's view was never carefully refuted at the time. It was simply dismissed as politically incorrect. President Carter's *Global 2000 Report,* for example, mostly ignored the Johnson view, and went on to forecast a future of tight rather than slack world market conditions.

Johnson's vindication was not long in coming. International commodity prices returned to trend levels after 1981, and the strength of Johnson's arguments was suddenly apparent to all. Some of the same politicians who earlier had excused their own protectionist farm programs through references to a "world food crisis" began looking anxiously for ways to reform those programs. They soon found themselves jointly promoting precisely the course of action that Johnson had earlier recommended: a multilateral liberalization of farm programs through GATT. They even usurped a Johnson term, disarray, to describe the international farm market structures they were now trying to alter.

While Johnson's second edition understandably devotes some time to documenting the prescience and accuracy of his earlier views, he offers much more. The price fluctuations of the 1970's and 1980's are explained by showing how the policies he criticizes, which are designed to promote price stability within states, will naturally lead to exaggerated price instability in international markets. The macroeconomic sources of these price fluctuations are also treated briefly in this new addition (yet they remain something of a secondary consideration in Johnson's style of analysis).

He recognizes the large and important body of scholarly work which has modeled and quantified various international market distortions since 1973. Professional economists will likely find this information to be the most interesting feature of the second edition. Johnson's contribution here is his practical taste for describing market distortion in language useful to politicians and policymakers, not just professional economists.

This new volume speaks directly to contemporary policy concerns by discussing prospects for farm market liberalization in the continuing Uruguay Round. Johnson wants the Uruguay Round to bring industrial countries toward a systematic liberalization of current policy. He proposes gradual multilateral support reductions and a "transition programme" of decoupled income supports, plus investments in improved education and alternative job training for rural farm youth.

Each reader will find points of disagreement with some of Johnson's stronger arguments. My own view is that Johnson has placed far too much faith in GATT as a promising venue for farm policy reform. Johnson's belief (p. 302) that policy reform will come only through *multilateral* actions (presumably in GATT) is not supported by any recent historical evidence. Both the United States and the European Community, under severe budget pressures, have recently undertaken significant support reductions unilaterally, and Japan has negotiated bilaterally with the United States, all this outside of GATT. The most significant consequence of trying to reform agriculture in the Uruguay Round, so far, has been a negative one: to paralyze all nonagricultural progress in the Round.

Johnson's emphasis also remains (as in the 1973 edition) too heavily focused on the EC. Beyond Europe, efficient farm trade expansion is still possible without the kind of liberalization that so concerns Johnson. In Japan, and especially among East Asia's newly developed countries, farm trade

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has recently expanded through rapid income growth and dietary enrichment. One suspects that Johnson, if he had spent time examining such countries, would have faulted them for their high nominal rate of protection, rather than congratulating them for the spectacular trade expansion that their rapid income growth has recently made possible.

By focusing so heavily on farm sector protection in the developed countries, Johnson implies that most of the "disarray" in world agriculture would end if policies in these rich countries could only be reformed. Most of the world's farmers, however, live in poor countries, which tend to tax the farm sector excessively, rather than provide protection. Here, it could be argued, are the agricultural policies that most need reform. From the perspective of social justice as well as efficient resource use, a treatment of disarray ought to say more about these government constraints.

Local Organization Helps Make Sound Land Reform

Agrarian Reform and Grassroots Development: Ten Case Studies. *Edited by Roy L. Prosterman, Mary N. Temple, and Timothy M. Hanstad. Boulder, CO: Lynn Rienner Publishers, 1990, 339 pages, $34.*

Reviewed by William C. Thiesenhusen

Land reform may not be fashionable these days, but it remains a component of sound agricultural policy in many countries. The 10 case studies featured in this book make that abundantly clear. The urgency of agrarian reform is stated succinctly, if in exaggerated fashion, by Jannuzi and Peach: "The technical knowledge needed to increase food (and nonfood) production significantly in Bangladesh already exists.... [W]idespread poverty in Bangladesh is not primarily due to a population that has grown too large, a scarcity of natural resources, or the constraints of an unalterable production possibilities frontier. The primary impediment to economic progress in Bangladesh is the traditional system of relationships of people to the land" (p. 78).

The authors illustrate the shortcomings of present agrarian reforms in Bangladesh. Especially valuable is their discussion of the traditional system of a "layered" hierarchy of rights in which many workers are accommodated on one piece of land. Those with prime authority acted on behalf of the state as revenue-collecting agents *(zamindars)*. Beneath them figured various categories of tenants who paid rents and had specified conditional rights in land. The system was complex and stratified. The land reform legislation of 1950 abolished *zamindars* as rent collectors for the state, but installed them as *maliks,* or landholding tenants of the state, which changed the system little.

Without precautions, old elites often become new elites after reform. Controlling the post-reform behavior of these notables is difficult, because they are skilled in exploiting new situations for their own benefit. The world over, reform does not blunt opportunism. After the Bolivian agrarian reform, for example, some expropriated landlords became oligopsonists in beneficiary output marketing.

The Bangladesh situation also illustrates that intended beneficiaries of reform are often bypassed in fact (a point supported by the meager Latin American land reforms of the 1960's and 1970's, which provided estate workers with land, but seldom rewarded the landless wage laborer).[1] Bangladeshi sharecroppers and agricultural laborers did not obtain land in the reform either. Indeed, only minor changes were made to the basic land reform law after Bangladesh was split from Pakistan, and none of them altered the land system significantly. Legislation of one type or another was passed but not implemented. As *maliks* appropriated land, half of all rural households became functionally landless with the number growing. Land reform in Bangladesh was a Potemkin village, existing only on paper.

Contrasting with Bangladesh is Herring's study of Kerala, India, where land reform broke the back of landlordism and gave rise to a new group of landlords *(jenmis)* who were former tenants. "The new *jenmis* are nothing more nor less than petty capitalist farmers maximizing profits" (p. 69). Herring concludes, "The obvious parasitism of the rentier ... is not matched by the newly landed proprietors, who know agriculture and organize production" (p. 69). Herring carefully traces the birth of land reform in Kerala, explaning why it is so different from

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[1] For more information, see *Searching for Agrarian Reform in Latin America,* ed. William C. Thiesenhusen, Boston: Unwin Hyman, 1989.

the rest of India in the manner in which it treats social problems. Kerala gives priority to eliminating illiteracy and permits extensive politicization of the underclass. The strength of the land reforms in Kerala is that participatory democracy, which had been established at the grassroots before reforms, was empowered by the agrarian changes.

The editors believe that grassroots support is vital to make certain that land reform is honestly and efficiently executed. But they also see a need for strong central authority at the time the reform is executed. The key is "a resolute center act[ing] in conjunction with local mobilization and cooperation" (p. 315). I agree, but the proper mix is difficult to achieve. Local planning committees were successfully organized in opposition to the landed elite during the post-World War II land reforms in Japan, but what seems to be a similar formula, according to Riedinger, appears not to be working well in the Philippines.

Bangladesh and Kerala illustrate that agrarian reforms in the same part of the world can have very different outcomes. Surely a prime factor in land reform success would be a committed government and an organized, empowered, and relatively homogeneous peasantry. Another vital attribute of a successful reform is the ability of the government to grant clear and unambiguous tenure rights, preferably in perpetuity, to the peasants. In their fascinating analysis of the social responsibility system (SRS) in China, Prosterman and Hanstad find that the government will have to privatize peasant plots completely to obtain the investments needed to improve agriculture. Neither 15-year use contracts, which seem to be most prevalent in the countryside since SRS was instituted in the late 1970's, nor increased prices seem to be able to stimulate production again (after its impressive surge into the early 1980's). The Chinese case leaves no room for doubt: incentives matter, and when they are clear, agrarian reform has the best chance for success.

Making inputs, agricultural knowledge, and credit available to new owners are steps often overlooked in agrarian reforms. Grindle underlines this well in her chapter, appropriately subtitled "a cautionary tale." She concludes that while about 70 percent of the farm units and 50 percent of the land in Mexico are now in the reform sector, most public policy assists the private, commercial sector and bypasses the agrarian reform beneficiaries and small landholders. Thus, Mexican agriculture produces below its potential and staples are imported.

Outside help can assist the process, but the decision to reform is domestic. Scofield eloquently pleads for more U.S. support for agrarian reforms in Central America, partly to preclude prolonging civil war over agrarian inequities. While the United States may not have much aid to give, Scofield suggests a system of "reverse preferences [in trade policy], in which Costa Rican, Honduran, or Salvadoran exports receive higher quotas than countries such as Guatemala [which has only token reforms], whose policies were determined to constitute a threat to the security of the region" (p. 167).

We are also reminded in this volume that, in some countries, land policy reforms are high on the policy agenda. Weiner's chapter on South Africa makes this clear, though rapid events there have already relegated whole sections of this chapter to history. The African National Congress is pushing ahead with its agrarian reform plans, apartheid is crumbling, and legislation now permits blacks to buy land in previously white areas, though, of course, their lack of funds makes this nearly impossible.

Brooks, who covers the former Soviet Union and Eastern Europe, hints that the former U.S.S.R. may be able to learn from Poland's largely private farming and Hungary's more eclectic blend of collective and private agriculture. The former Soviet Union cannot privatize its agriculture in the way China did, because it has no peasant class. The country is

The essays include: "Introduction" by Roy L. Prosterman, Mary N. Temple, and Timothy M. Hanstad. **Asia:** "Philippine Land Reform in the 1980s" by Jeffrey Riedinger; "Explaining Anomalies in Agrarian Reform: Lessons from South India" by Ronald J. Herring; "Bangladesh: A Strategy for Agrarian Reform" by F. Tomasson Jannuzi and James T. Peach; "China: A Fieldwork-based Appraisal of the Household Responsibility System" by Roy L. Prosterman and Timothy M. Hanstad. **Latin America:** "Land Reform in Central America" by Rupert W. Scofield; "Agrarian Reform in Mexico: A Cautionary Tale" by Merilee S. Grindle; "Land Tenure and Land Reform in Brazil" by Anthony L. Hall. **Soviet Union and Eastern Europe:** "Land Tenure in Collectivized Agriculture: The Soviet Union, Poland, and Hungary" by Karen M. Brooks. **Southern Africa:** "Ten Years After: Land Redistribution in Zimbabwe, 1980-1990" by Michael Bratton; "The Land Question in South Africa" by Daniel Weiner. **Conclusion:** "Issues for the Near Future" by Prosterman, Hanstad, and Temple.

several generations away from individual farming, which is far different from the situation in China, where communes were introduced in the 1950's.

Speed and type of land reform in the former Soviet republics will vary among and within the separate states. A great deal of research needs to attend policy changes there, especially since few collective and state farmworkers have indicated a preference for private property. Workers in collective agriculture have become accustomed to a system of wages, perquisites, and 8-hour days. What will happen when enormous agricultural subsidies are eliminated and agriculture is privatized is anybody's guess.

An imaginative combination of private individual and group-held farms may work well, provided former collective and state farm members have a voice in matters of reorganization, unhindered by present farm administrators. One can easily foresee some of the large farms in Kazakhstan surviving as subsidies are cut, while in the Ukraine much more family farming might result. Also, there is need to reform input and output markets so the growing private sector can be serviced. Today this sector sells its products (and buys its inputs) through the collective sector (which takes its bite and thus dampens private-sector incentives). Other troublesome facts are that to date the incipient private farming movement in the former Soviet Union is concentrated on inferior land, and it lacks capital resources and extension help.

The message from this collection of essays is that no one model exists for agrarian reform, and reforms are by nature untidy. Post-reform tenure patterns need to be shaped to local conditions, history, and factor markets. Also, there must be close correspondence between effort and income received. Farm-level incentives are important, but so is post-reform attention to inputs, services, and technology that will stimulate production. The unfortunate truth is that often more political mileage can be obtained from distributing land than from assisting beneficiaries on that property to increase their production and thereby their incomes. I would have liked information from microstudies, as in the chapters on China, Brazil, and Kerala. More emphasis on income distribution and employment creation would have helped, though I realize that little such information is readily available.

Philippines Offer Refreshing Perspective on Rural Credit

Informal Credit Markets and the New Institutional Economics: The Case of Philippine Agriculture. *By Segrario L. Floro and Pan A. Yotopoulos. Boulder, CO: Westview Press, 1991, 146 pages, $23.50.*

Reviewed by William F. Hyde

In the foreword to this tidy little book, Joseph Stiglitz points out that rural credit has become a priority issue for economic development. The general focus of concern is with the availability and terms of rural credit, and with government's failure to drive informal money lenders from the market for rural credit. Floro and Yotopoulos provide an empirical assessment of rural credit within the framework of information economics (the New Institutional Economics). They justify this framework on the grounds that information imperfections are pervasive and important in less-developed and rural areas.

The book begins with testable propositions about the price-quality theorem of credit markets in developing countries. This theorem states that an increase in the rate of interest for the purpose of equating supply and demand is likely to affect loan quality by reducing the probability of repayment.[1] That is, high-quality borrowers will seek credit elsewhere or depart from the market altogether, leaving only borrowers who are more likely to default on their obligations. Furthermore, high interest rates are more likely to attract borrowers with risky projects and greater probability of default. Together, these effects imply that the expected returns on loans do not fully compensate for increasing the interest rate. The result must be credit rationing among borrowers who are otherwise indistinguishable to the lender.

Floro and Yotopoulos use ANOVA and regression techniques on a survey of 111 agricultural borrowers and lenders from three provinces in the Philippines to test these propositions. Their results point out that both lenders and borrowers are heterogeneous, that the formal terms of credit (interest rates, collateral) do not necessarily rise with the default rate on loans, and that lenders from the for-

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[1] J. E. Stiglitz and A. Weiss, "Credit Rationing in Markets with Imperfect Information," *American Economic Review*, vol. 71, no. 3, pp. 393-410.

mal and informal credit sectors both have the same problems of sorting information, providing incentives, and enforcing repayment. Formal sector lenders, however, are at a greater information disadvantage in any local community. The authors conclude that formal and informal sector lenders are complements, not the substitutes usually assumed by central governments, international development agencies, and many neoclassical economists.

This intuition is refreshing and enlightening to me, as a student of development and of the Philippines. I rapidly became an enthusiastic reader of this book.

Floro and Yotopoulos's empirical investigation goes beyond price adjustment and collateral requirements. They ask what completes the sorting of heterogeneous borrowers in competition among heterogeneous lenders. They begin by explaining that risk originates with the borrowing (not lending) operation of formal financial institutions. That is, institutions using expensive money must charge higher lending rates. This leads them to adverse selection of risk and to increased probability of borrower default. Thus, we observe in U.S. S&L's and in the Philippines since deregulation in 1981 unanticipated adverse selection of risk in bank borrowing and moral hazard in lending—and bank failures.

The authors then formulate tests to support their propositions, and follow with their empirical results and policy conclusions. I do not know the New Institutional Economics (NIE) well enough to judge their success in terms of it. NIE aside, however, their evidence did improve my understanding of informal credit markets.

Floro and Yotopoulos observed four general classes of actors in the rural credit market, two lender classes and two borrower classes. **Trader-lenders** (formal market lenders) avoid adverse selection of risk. For them, the lending rate is a decreasing function of borrower income and an increasing function of the perceived probability of default. **Farmer-lenders** (informal lenders) may prefer risk if it increases their opportunity to obtain the borrowers' defaulted property. Their lending rate can be an increasing function of borrower income. **Wealthy borrowers** generally find credit in the formal market. **Poorer borrowers** generally rely on the informal market.

The authors also observe that the formal sector (trader-lenders) has limited funds to lend and incomplete information on local borrowers. The formal sector has better information on the creditworthiness of wealthy borrowers. Some wealthy borrowers become farmer-lenders, and they have the advantage of knowing their community better than the formal lenders. Therefore, they are in a better position to know the creditworthiness of poorer borrowers. Furthermore, credit rationing in the formal sector alters the size of loans but does not alter the identity of the borrowers. Large farmers continue to be the formal sector borrowers. The only effect on them, as rationing becomes more constrained, is that they obtain lesser amounts of credit per borrower.

This sequence of observations suggests a layering of formal and informal financial institutions, and the author's residuality hypothesis: When credit is rationed, personal relationships in the informal sector manage the adverse selection of risk. The informal sector completes the sorting of scarce investment capital.

The policy implications are that the formal and informal sectors are complements. Where credit becomes the key to increased agricultural inputs (therefore, increased output), the informal sector plays a beneficial role by reaching borrowers that the formal sector cannot. The more distressing policy implication is the negative equity consideration. Large farmers may use their second role as farmer-lenders to encourage high-risk activities, leading to subsequent default by small farmer-borrowers.

I have always found the study of financial institutions tedious. Perhaps the tedium is explained by the propensity of most work on rural credit to explain the history of local institutions and public action without creating a conceptual organization for the obvious layering of the formal and informal lending sectors. Floro and Yotopoulos filled the void for me. Their thesis and my intuition would argue that the very high terms of credit observed in rural areas and developing countries are indicative of the critical nature of the credit input to rural economic activity.

I am unsure that the authors need all the nice words about the New Institutional Economics. They have created a tightly organized, readable, intuitively satisfying, and rigorous discussion of the principal actors in the Philippine market for rural credit. We might anticipate that similar actors operate with similar objectives and cause similar policy implications in other cultures. Yet, I suspect that we need a few more examples to convince the central lending authorities and the international aid agencies of the complementarity of the formal and informal sectors of the credit market.

I also wonder what Floro and Yotopoulos can do with their distressing equity conclusion. Should we be concerned about protecting small farmers from aggressive, large farmer-lenders? How great is this problem, and what are the controls on it? Small borrowers in some countries pool their resources and obtain the means to set up their own lending institution. Of course, these small borrowers have the information that allows them to avoid adverse selection of risk when lending to themselves. Do these pooling arrangements give us any insight?[2] Floro and Yotopoulos took us most of the way in good style. Their good book would have been even better if it had closed with their reflections on the equity problem they raise.

Why Aren't More Economists Rich?

If You're So Smart. *By Donald N. McCloskey. Iowa City: Univ. of Chicago Press, 1990, 190 pages, $17.95.*

Reviewed by Clifford Dickason

In this, his most recent book, University of Iowa economics professor Donald McCloskey sets out anew to support his contention that rhetoric is critical to both applied economics and establishing the validity of economic hypotheses. Economists are peculiarly vulnerable to a common American query, "If you're so smart, why aren't you rich?" Most economists are not rich. They are presumed to have achieved a thorough understanding of economic phenomena, especially markets. Yet, the question implies that competent economists would have a steady flow of income, gained from their informed speculating in real estate, commodities, and the stock market.

McCloskey singles out as especially flawed those modernist economists who employ only precise mathematical logic and purely objective data. He believes that they are not sufficiently critical of their own tendency to dismiss what may be best described as the numerous institutional and psychological forces that affect a nation's economy. He is not implying that modernist economists are incompetent. Rather, they fail to divine the results of continual change among institutions, producers, investors, and consumers. Precise mathematical conclusions easily fall victim to the vagaries of institutions and the psychology of human beings. He advises us that lucrative economic predictions are more in the realm of art than science and wisely reminds us that it is futile to pretend that humanity is predictable within the modernists' context of objective data and flawless mathematical logic.

McCloskey demonstrates that the era of modernism, or pure logical positivism, has ended for several sciences, replaced by scientific convention that employs rhetoric. Philosophy, which had experienced a modernist phase, led the way. Physics, astronomy, and other sciences followed. The author persuasively argues that economic hypotheses, even if ostensibly tested by strictly logical analyses of purely objective data, have usually been judged by their proponents' rhetoric and the torrent of opposing discourse and debate before a rhetorical consensus is reached. The debaters have been economists who were familiar with the subject matter.

The author demonstrates that the rhetorical consensus process for judging the realism of economics generalizations usually and justifiably includes a tetrad of basic rhetorical components: objective data, logic, metaphors (that is, models), and storytelling. Storytelling is defined as describing economic phenomena in an eclectic manner, which usually brings together objective facts and constraints based on logic, institutions, conventions, history, and psychological factors. The story narratives usually take the form of extended, multifaceted generalizations based on established economic theory and common features of similar historic occurrences.

McCloskey commends the modernists' fascination with the perfection of abstractions, but to behave and write as though no legitimate research can be done beyond the realm of objective facts and precise mathematical logic is to perpetuate a methodological dogma. Economists can provide more utility to society by including messy realities and "*un*-sterilized" data in their analyses.

An analogy from the phenomenon of falling objects illustrates McCloskey's theories on how modernist economists go wrong. Sir Isaac Newton discovered

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[2]This issue has been debated in the context of Indian agriculture. For a survey, see P.K. Bardhan (ed.), *The Economic Theory of Agrarian Institutions,* Oxford: Oxford University Press, 1989.

through a careful, mathematical process how gravitational attraction influences the trajectories of celestial bodies, artillery shells, and satellites. Still, objects like parachutes, feathers, and gliders tend to reach terminal velocities when falling in air. Shortly after they head downward, they virtually ignore the Newtonian formula governing acceleration from gravity. Their paths are governed mainly by rather complicated forces and resistances that slow the descent. Predicting their paths' orderly or chaotic randomness is only roughly possible and even then is based upon repeated trials and observations.

The changing forces and resistances of institutions and other human behaviors mirror the complex phenomena that govern how an object falls through air. Although all firms strive for high profits, enterprises are affected differently by changes in consumer and investor thinking and by institutional changes. Business fortunes are analogous to the flight paths of somewhat different gliders which alter course from one temporary thermal updraft to another, singularly buffeted by lift, turbulence, and downdrafts.

The author persuasively contends that economic analysis should be rigorous, but that "rigor" need not necessarily mean "quantitative exactness" and should not mean ignoring some of the key evidence that is available. He correctly believes that subjective survey response data have an important place in applied economics and that researchers who shun subjective data needlessly handicap their research. To describe this handicap, he uses the apt simile of a drunk who always searches for lost car keys beneath a lamppost because the light is better there.

If You're So Smart constitutes a wake-up call for economists to recognize explicitly that most of their group, in daily analyses and predictions, make use of more than the mere facts, metaphors, and logic that professional economics journals commonly display. To all economists who suspect that exact-science pretentiousness dominates current academic economics publishing, McCloskey's thesis will seem refreshing, like the remark of an observer who unselfconsciously points out that his emperor has been sold an imaginary suit of clothes.

This book is a compendium of historic economics wisdom that can add greatly to an economist's recognition and use of the storytelling that is essential to economic analyses.

In summary, McCloskey argues that economics, like other sciences, is destined to remain dependent on that tetrad of rhetoric if it is to be a provider of useful information. He believes that modernist economists, with their pristine mathematical abstractions, tend to studiously assume their way out of practical applications. The changeability of human motivations and institutions must be included within the economic framework. McCloskey's clear writing style elucidates this compelling argument.

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